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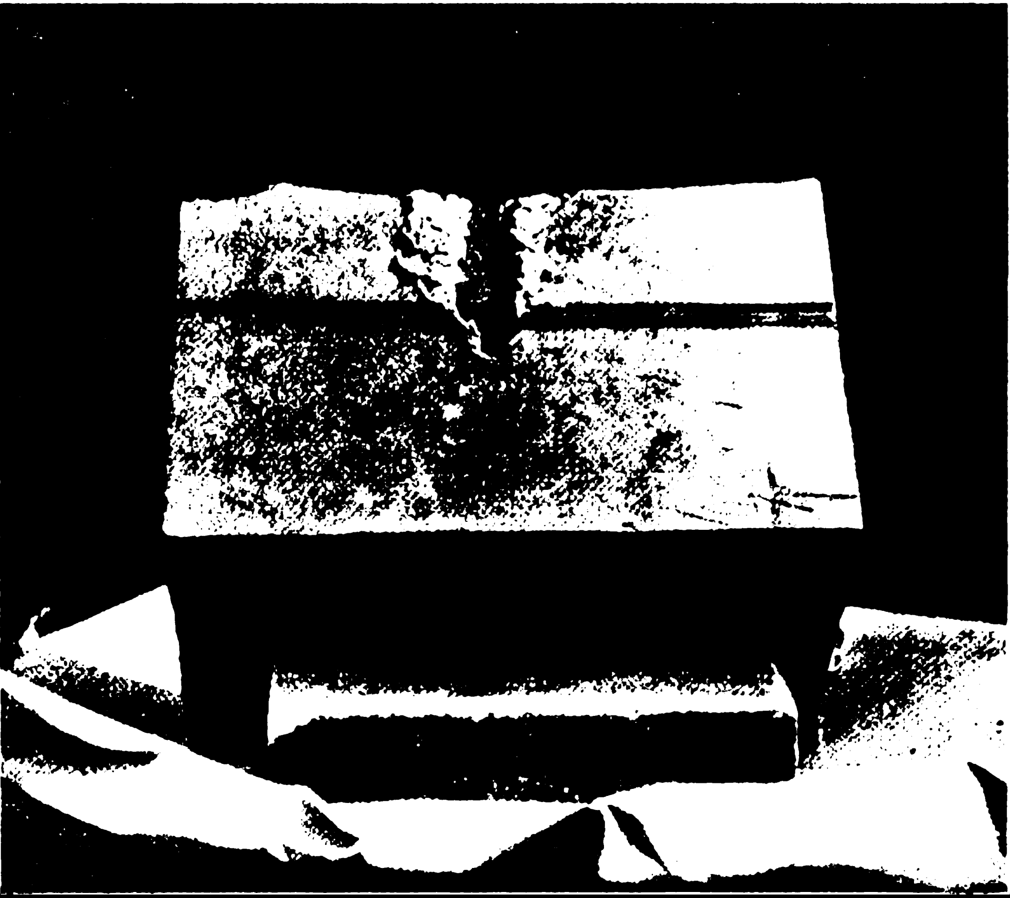

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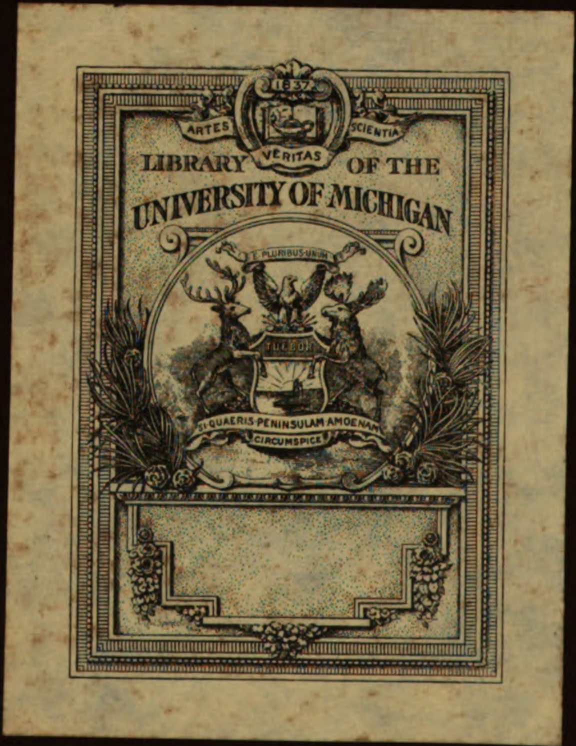

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THE JOURNAL

132,214

OF THE

IRON AND STEEL INSTITUTE

VOL. LVIII.

EDITED BY

BENNETT H. BROUGH

SECRETARY

LONDON
E. & F. N. SPON, LIMITED, 125, STRAND
NEW YORK: SPON & CHAMBERLAIN, 12, CORTLANDT STREET
SOLD ALSO AT THE OFFICES OF THE INSTITUTE
28, VICTORIA STREET, LONDON, S.W.
1900

Printed by Ballantyne, Hanson & Co.
At the Ballantyne Press

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THE
IRON AND STEEL INSTITUTE.

SECTION I.

MINUTES OF PROCEEDINGS.

PARIS MEETING.

The Autumn Meeting of the Iron and Steel Institute was held at the house of the Société d'Encouragement pour l'Industrie Nationale, 44 Rue de Rennes, on Tuesday, September 18, 1900—Sir William C. Roberts-Austen, K.C.B., President, in the chair.

Reception of the Institute.

Mr. Robert de Wendel (the President of the Société d'Encouragement pour l'Industrie Nationale), in gracefully welcoming the Institute to Paris, said: Gentlemen, my confrères on the Reception Committee have done me a great honour in selecting me to bid you welcome. This welcome comes from the bottom of my heart, and I only regret one thing, and that is that my ignorance of the English language does not allow me to make myself properly understood by you. I have had the honour of being a member of your Institute for more than thirty years, and if I have not taken an active part in your work, I can only put the blame on this unfortunate ignorance of the English language; but I have never ceased to follow it with the greatest interest. I have read all the reports about it, and I can assure you that the collection of these reports forms to-day the most interesting and useful collection for every metallurgical engineer wishing to acquaint himself with the history of our industry for the last quarter of a century. I do not wish to take up your time any longer. I once more bid you welcome, and I make way for your President, who will preside over your debates. I have no doubt but that this meeting will be as fruitful in good results as all the preceding ones have been. I wish for no better earnest of that than the list of subjects which are going to be offered for your deliberation.

The PRESIDENT, who spoke in French, replied as follows:—For the third time the Iron and Steel Institute, as a body, receives the cordial hospitality of the Société pour l'Encouragement de l'Industrie Nationale. We cannot, therefore, consider ourselves as strangers, but rather as the habitual guests at a friend's house. We feel ourselves at home, because of the many members of the Comité des Forges assembled together to receive us, and the friendly relations which subsist between the Comité des Forges and our own Institute. My vocabulary, I regret to say, is a limited one, but it contains the word "gratitude," and that is the word I want, Mr. Robert de Wendel, to express to you the feelings of the members of the Iron and Steel Institute, in whose name I have the honour of speaking, and whom I introduce to you to-day. The members of the Comité des Forges and of the Institute can meet together with brotherly cordiality on the occasion of this splendid International Exhibition, a work wholly of peace and good-fellowship, which crowns so nobly the end of the century. We are very glad to bring to you from England our warmest congratulations on the work which France has just accomplished. Does it not remind you that it is the ironmasters of the whole world, and particularly those of France and England, whose industry has given to this century the name by which it will be known by future centuries—that of the "steel age"? We are most grateful for your reception, and we are sure that our meeting will only add to the many bonds which unite France and England.

Mr. HENRI DE WENDEL (Bessemer Gold Medallist) said: I thank you for the great honour you have done me in conferring upon me this year the Bessemer medal. I think that the medal should really have been given to my much regretted master, Professor Jordan. Unfortunately he died some time before the meeting, and therefore, that being impossible, you have doubtless wished to honour the professor by conferring the distinction upon one of his pupils. That must, I think, have been your reason, for my own merits are too small to aspire to such a great honour. However that may be, I am very grateful to you. In 1889 we had the pleasure of receiving among us a great number of the members of the Institute. At that time we were quite content in showing you our foundry, because, thanks to having made the puddling quite mechanical, and also to having supplied the rolls with reversing engines, we had a foundry which could be considered, from the point of view of making puddled iron, as the most advanced of any. But when you came to visit us, I think it was really to be present at the dying moments of puddled iron and to attend its funeral; for very shortly after you had before you the remarkable paper of our regretted friend Mr. Thomas and of Mr. Gilchrist, which was to entirely modify the conditions then obtaining. We have now constructed the Joeuf and Hayange foundries and steelworks; that means that the works which you are going to visit are not the most recent ones, since they are already twenty years old. I ask the forgiveness of all seekers after novelty, for they will not find any in the Bessemer department. It dates twenty years back. With regard to the rolling-mills, I hope to show you something more interesting. Thus in advance I make every apology for the somewhat old-fashioned part of the works which you will visit; but I am, nevertheless, very happy to receive the members of the Institute, and feel very honoured in doing so.

The **SECRETARY** read the minutes of the previous meeting, which were confirmed and signed.

Mr. W. **CROOKE** (Frodingham) and Mr. R. G. **SCOTT** (Leeds) were nominated scrutineers, and on the completion of their scrutiny announced that the following gentlemen had been duly elected members of the Institute :—

Name.	Address.	Proposers.
Bamber, Herbert Kelway	utta, Bengal, India	Sir William Roberts-Austen H. Kelway Bamber, Septimus Young.
Beard, Herbert . . .	Gartcosh, near Glasgow	Arch. Colville, Thomas Davie, Walter Dixon.
Beattie, Francis. . .	Moss Bay, Workington	John S. Randles, William Burnyeat, James Crawford.
Bond, Henry Coulson	3 Love Lane, Eastcheap, London, E.C.	J. T. Smith, Ernest Trubshaw, R. Beaumont Thomas.
Charlton, Alfred Johnson	886 Ashton Old Road, Manchester	Edward P. Martin, E. Windsor Richards, Sir William Roberts-Austen.
Charlton, William Johnson	7 Victoria Street, London, S.W.	Edward P. Martin, E. Windsor Richards, Sir William Roberts-Austen.
Cowper-Coles, Sherrard Osborn, Assoc. M.Inst.C.E., M.I.Mech.E.	Grosvenor Mansions, Victoria Street, London, S.W.	F. W. Harbord, Thomas Twynam, Edward P. Martin.
Davis, Charles Henry	99 Cedar Street, New York City, U.S.A.	G. E. Macarthy, H. H. Campbell, Walter M. Musgrave.
Dodgson, Thomas Edward	Park Gate Iron and Steel Company, Ltd., Rotherham	Charles Markham, John D. Ellis, C. J. Stoddart.
Dronfield, Joseph Herbert	Descanso, Alexandra Park, Oldham	Henry Webb, Thomas Ashbury, Joseph Gregory.
Frielinghaus, G. . .	Essen, Germany	Edward P. Martin, Otto Eichhoff, A. Tannett Walker.
Gaunt, John Thomas .	9 Swinburn Road, Egglescliffe Junction, R.S.O., Durham	John Law Smith, Henry Tomkins, James Bott.
Gaunt, Richard . . .	Albany Villa, Egglescliffe, R.S.O., Durham	John Law Smith, Henry Tomkins, James Bott.
Gwynne, Thomas . .	Briton Ferry, Glamorganshire	William Evans (Cyfarthfa), Herbert Eccles, Lewis Jenkins.
Harris, Henry Graham, M.Inst.C.E., M.I.Mech.E.	5 Great George Street, Westminster, London, S.W.	E. Windsor Richards, Edward P. Martin, A. Tannett Walker.
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Hasebe, Kosamuro. .	Cyclops Works, Sheffield	Sir Alexander Wilson, Thomas Nash, F. J. Maw.
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Hedley, George . . .	Messrs. Bolckow, Vaughan & Co., Middlesbrough	Sir Lowthian Bell, David Evans (Middlesbrough), Edward P. Martin.

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Melland, Godfrey, B.Sc., Assoc.R.S.M., F.I.C.	Mason University College, Birmingham	John W. Hall, Harry Silvester, Alex. E. Tucker.
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Orme, Reginald Thomas	The Woodlands, Uttoxeter New Road, Derby	B. J. Broadway, Ewing Matheson, Edward P. Martin.
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Ridley, James Cartmell, jun.	Swalwell Steel Works, Newcastle-on-Tyne	J. Cartmell Ridley, John B. Simpson, Ernest Scott.
Roberts, John Frederick Mitchell	Park Lodge, Eltham, Kent	Sir William Roberts-Austen, Sir F. A. Abel, Edward P. Martin.
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Torbock, John Ernest	c/o Messrs. Wild & Co., Middlesbrough	Arthur Cooper, Illtyd Williams, J. E. Stead.

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Turner, John Hamilton	129 Trongate, Glasgow	G. MacLellan Blair, J. C. Cunninghame, E. Windsor Richards.
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Williams, Samuel . .	Ffosyrefel, Pontardulais, Glamorganshire	Edward P. Martin, John R. Wright, Isaac Butler.

THE PRESIDENT-ELECT.

The PRESIDENT said he had one singularly pleasing duty to perform, and that was to announce the name of the new President, who would at the Spring meeting occupy the chair. The choice of the Council, as they would all be glad to hear, had fallen upon Mr. William Whitwell. He had a claim not only of seniority, but of merits of many kinds, which it would be impossible to dwell fully upon. It was a choice the excellence of which would reveal itself when Mr. Whitwell took his place in the chair in May next. This was not the opportunity to dilate on Mr. Whitwell's qualifications for the post, and he would merely add on his own part how glad he was that Mr. Whitwell would be his successor.

THE ANDREW CARNEGIE DONATION.

The PRESIDENT said he had another announcement, also of a pleasing character, to make. It was no less than a communication from Mr. Andrew Carnegie, Vice-President, who, at the conclusion of the last meeting, announced his intention of giving a medal and a scholarship in connection with the Institute, to be devoted to research and for a piece of work of some definite kind. The details were not actually arranged as yet, but he might say that the work would be performed in any university or any works, irrespective of nationality and sex. When they remembered the work done by Madame Curie, by Mrs. Ayrton, and by Miss Ella Bryant at the present time, it was the very least that they could do to give women a chance of securing such a scholarship. He would read the message sent to him by Mr. Carnegie :—"My dear Sir William,—I shall be delighted to hand over £6500, as you suggest." He might add that Mr. Carnegie was not quite correct in saying that he suggested it; he merely ventured to ask what sum Mr. Carnegie would wish to give, and he answered £6500. Mr. Carnegie continues :—"Please arrange all details and let me know, and I shall send cheque. I am sorry that I cannot attend the meeting, which I hope will be a great success." He was sure that they would wish him to convey to Mr. Carnegie the thanks of the Institute for this munificent gift.

THE RETIRING VICE-PRESIDENTS AND MEMBERS OF COUNCIL.

The SECRETARY announced, in accordance with Rule 10, that the Vice-Presidents and the Members of Council who would retire by rotation in May next were :—Sir John G. N. Alleyne, Bart., Mr. George James Snelus, and Mr. James Riley, Vice-Presidents; and Mr. John Devonshire Ellis, Mr. Robert Abbott Hadfield, Sir Benjamin Hingley, Bart., Mr. William Beardmore, and Mr. David Evans, Members of Council. All these gentlemen were eligible for re-election. It was competent for members to nominate candidates for office up to one month previous to the general election.

THE VISIT TO THE PARIS EXHIBITION.

The SECRETARY announced the arrangements made for dividing the members into groups for seeing the contents of the Exhibition with greater facility. He said they were to meet at the British Section in the Palace of Mining and Metallurgy, where they would be divided into five groups, each under the guidance of a French engineer, who would wear the Institute badge with a tricolour ribbon. The different parties would be taken round the metallurgical exhibits, and the exhibitors would be present to give information. The members would proceed to the Le Creusot Pavilion, where they would be entertained by Mr. Schneider. A letter had been received from the American exhibitors in mining and metallurgy, who cordially extended a welcome and entertainment to the members visiting the Exhibition.

THE PRESIDENT'S ADDRESS.

The PRESIDENT said he had prepared a Presidential Address which had been beautifully translated into French. He did not propose to read the address in full, in order that they might have more time to see the metallurgical contents of the Exhibition; but he hoped that the members would read it for themselves, and he might say that he wished to emphasise that part of it which showed the close union of the works of France and England in connection with iron and steel throughout the century.

The following is the President's address:—

PRESIDENTIAL ADDRESS

INTRODUCTION

THE following Address was delivered in Paris on the 18th of September 1900, and transmitting it in the closing days of the year to the pages of the Journal of our Institute, enables me to express my grateful thanks for the singularly appreciative reception accorded to it in France. This is in no small measure due to the grace of the beautiful prose in which my friend M. Osmond's translation rendered it. The Address was written in the confident hope that the bonds which have long united the scientific and industrial workers of France and England would be rendered far more comprehensive than they are, if the peoples of our respective countries better understood the interdependence of their work and interests. The reception of the Address shows that the view that permeates it only needed the most simple expression to ensure sympathetic response, and to reveal the widespread existence of similar views to those it embodies. The warmth of our greeting in France, and the personal kindness shown to our members, was quite in keeping with the magnificence of the receptions and entertainments provided for us. We felt at home at once, meeting as we did in the house of the *Société d'Encouragement pour l'Industrie Nationale*, which was placed at our disposal for the third time in our history as an Institute. We are specially grateful to M. Robert de Wendel, President of the Comité des Forges, a Member of our Institute, who presided over the reception committee, which comprised many of the most eminent scientific and industrial men in France. I would also thank the Minister of Public Works, M. P. Baudin, who received us on behalf of the President of the Republic. We were grateful to M. Eugène Schneider, a Member of our Institute, who received us in the Exhibition at the very interesting pavilion of Le Creusot Works. In connection with Le Creusot, I would specially express our thanks to M. Gustave Canet for many acts of kindness, and for the reception which, as President of the *Société des Ingénieurs Civils de France*, he gave me when, earlier in the year, I visited Paris as one of the representatives of our Council. I am able to add, with great satisfaction, that M. Canet is now an Honorary Member of our Institute. As regards the excursions, M. A. de Montgolfier, who is, I am glad to say, also an Honorary Member of our Institute, received us munificently at the St. Chamond Works, while M. Henri de Wendel, our Bessemer Medallist, entertained a party at his works at Hayange and at Joeuf. The President of the Municipal Council of Paris invited us to the Hôtel de Ville, and M. Grébauval's eloquent and appreciative words of welcome will be remembered as one of the noteworthy features of the meeting.

Colonel and Mrs. Jekyll's delightful reception at the English House in the *Rue des Nations* at the Exhibition reminded us how close Paris is to London.

Not the least claim to our gratitude was earned by the generosity of Mr. Henry Chapman, who again placed his offices at our disposal; while the ability and indefatigable energy of M. Henri Vaslin, our Local Secretary for the Meeting, contributed greatly to its success.

I would end this brief preface by recording an incident which occurred at the first of the memorable receptions offered to us. A gifted actress, Mdlle. Marguerite Deval, incidentally appealed to the honoured name of Madame de Staël. Her unexpected allusion encouraged me to quote at a banquet which followed Madame de Staël's beautiful words, "*on depose fleur à fleur la courronne de la vie.*" They, however, suggest the gradual fading of human vitality, while the garland of the life of the century is enduring, for it is of steel, and the flowers and leaves composing it were gathered and entwined by the workers of both our nations, who hand it on untarnished to those whom future Presidents will, I trust, represent both in England and in France.

Christmas, 1900.

THE ADDRESS.

"It is an age so full of light, that there is scarce a country or corner of Europe whose beams are not crossed and interchanged with others, but there is none under heaven abounding with more variety of learning, where the sciences may be more fitly wooed or more surely won, than in France." These lines, written by Laurence Sterne in his incomparably clever "Sentimental Journey," were printed in the year 1768, the year in which Lavoisier's genius gained him admission as "Adjoint" to the French Academy, while at the same time the metallurgist Jars became "Membre titulaire." Sterne's is a glowing tribute, but we feel its justice and gladly adopt it as our own.

In the spring of 1899 I reviewed our national progress throughout the century in relation to iron and steel, and expressed the hope that at a future time I might give a similar account of the work in other countries. Our Institute is international, and some fifty of our members are either French or live on French territory; and as this is the third time that the Institute as a body has been hospitably received in France, my address may well be offered as a tribute to her. On both the previous occasions of our visits to Paris, as on the present one, the Société d'Encouragement pour l'Industrie Nationale generously placed its house at our disposal. In 1878 we were received, in the absence of the illustrious chemist, M. J. B. Dumas, then President of the Society, by Professor Gruner, and in 1889 by M. Gustav Eiffel and by M. Haton de la Goupillière. This year the President of the Société is M. Adolphe Carnot; this name, made illustrious by sons of France, who have filled the highest office in her army and in the State, will always be received with deep respect in England, and is imperishably connected with the advance of physical science. In my capacity of Professor at the Royal School of Mines, I am proud to claim M. Carnot as a colleague, and also M. Haton de la Goupillière, who again receives us; for I need not remind you that he presides over the École des Mines Institution, the distinguished professors of which have since its foundation advanced both industry and science. With these eminent professors representatives of the Comité des Forges have associated themselves, under the presidency of one who bears a most honoured name in metallurgy. M. Robert de Wendel is, moreover, one of our earliest members, and thus connects two institutions of ironmasters whose aims have so much in common, and whose efforts have always been directed to the advancement of the science and practice of the metallurgy of iron and steel. In 1878 Sir William Siemens, our President, dwelt in his brief address on the advantages France enjoys in her admirable system of scientific and technical instruction, while in 1889 Sir James Kitson, who presided over us, contented himself with a few graceful words of acknowledgment, and none could offer such words better than he. At the end of the century, I shall be expected to cover a wider range of observation, and to pass in review certain phases at least of the iron and steel industry. I may, however, say at once that the impression given by the most comprehensive view it is possible to take of it admits of concise expression in a brief statement. It is that the main characteristic of the metallurgical work of the century has shown the interdependence between minute quantities of matter and the masses of metal in which they are hidden. The century's work has, moreover, to a great extent revealed the way in which the small quantities of added matter act, and it has been shown that they exert profound influences even in solid metals; the fact that certain varieties of steel are "solid solutions" is now accepted, and the recognition of molecular movements in solids has become familiar. In no branch of work has the outcome of such knowledge been more striking than in the one to which all of us here are, in different ways, devoted. Metallurgists have again and again shown that no dependence is to be placed on the once famous maxim of the Duc de la Rochefoucault that "ceux qui s'appliquent trop aux petites choses deviennent ordinairement incapables des grandes." The influence of the apparently little on the obviously great is recognised, and we say with Browning—

> "Well, sir, the old way's altered somewhat since,
> And the world wears another aspect now;
> . . . .
> The small becomes the dreadful and immense."

The result is remarkable. The metallurgist, by adding small amounts of matter to iron, has literally made it possible to change the aspect of the world. He has enabled such structural triumphs as the Eiffel Tower and the Forth Bridge to be designed and built: he has created the Age of Steel, and of this age the palaces we have come to see on the banks of the Seine are the exponent, both as regards their construction and their contents.

Throughout the century, our nations have worked in unison, and shared the industrial triumphs by which the civilisation of the world has immeasurably gained.

The bonds of literature and of science have, moreover, for centuries united France and England, and the sympathy subsisting between men of letters stimulated industrial advance. In the thirteenth century Roger Bacon graduated as Doctor at the University of Paris before returning to Oxford, where his life's work was done. In the fourteenth century Chaucer translated the "Roman de la Rose." The great Scotch scholar, George Buchanan, an exile at Bordeaux, had Montaigne as his pupil, and Shakespeare in the "Tempest" and in "Hamlet" paraphrases sentences of Montaigne. In the seventeenth century Isaac Casaubon, coming as the guest of King James I., profoundly influenced English thought, and by reviving at Oxford the study of Aristotle, prepared the way for the advance of experimental science in our older universities. In the eighteenth century, Voltaire, meeting Benjamin Franklin in London, rejoices that he can speak his language. The Abbé Prévost translates "Pamela" and "Clarissa Harlow," and makes them known to French readers. Every page of the "Esprit des Lois" proves how much Montesquieu learnt from Englishmen, and especially, it may well be, from those living near his home at Bordeaux, among whom the father of our own great chemist, Black, was prominent. How much may not Black himself have owed to the kindly interest of Montesquieu in those early days on the banks of the Garonne? The literary union of the two countries was close, but the bonds of union in science were firmer and more enduring, as it is natural that they should have been, for the literary men discussed abstractions, the scientific men principles. The correspondence between Lavoisier and Black bears abundant testimony to the eagerness with which experimental results obtained in the respective countries were discussed. Reference was made in my inaugural address in the spring of 1899 to Lavoisier's tribute to Black, and I may now quote one sentence from a letter of the great Edinburgh Professor to his illustrious colleague in France. It runs thus—"Si le pouvoir de l'habitude empêche quelques-uns des anciens chimistes d'approuver vos idées, les jeunes ne seront pas influencés par le même pouvoir; ils se rangeront universellement de votre côté." This they did. Lavoisier welcomed our scientific men who visited France. How helpful to scientific progress must have been the month of October 1774, which Priestley spent in Paris; how interesting the dinner at Lavoisier's house when Macquer, who was present, hinted to Priestley that *plomb rouge* was too literal a translation, and that *minium* was the substance Priestley really had in view. Black died in 1799, and this brings us to the beginning of the present century, now so rapidly drawing to its close. It opened with a brilliant school of chemists in France, and as the names are familiar to us, would I could give you pictures of the men themselves; but Molière warned us, at a time when such sketches in words were fashionable, that "les portraits sont difficiles et demandent un esprit profond."

I must therefore refer you to Sir Humphry Davy, to whom the Emperor Napoleon gave permission to visit France, though the two countries were at that time unfortunately not at peace. Davy's vigorous hand and clear insight enabled him in friendly appreciation to preserve for us a few precious sketches in words which may be trusted, and may well be recalled. Berthollet he paints as being "modest, frank, and candid," with "no airs and many graces," while Vauquelin suggested to him "the mien and bearing of the French chemists of another age." Guyton de Morveau, Bonaparte's Master of the Mint and Baron of the Empire, was eighty years of age at the time of Davy's visit, and he says little of him. Gay Lussac, whom he placed at "the head of the living chemists of France," impressed him as being "profound, with great activity of mind and great facility of manipulation." Davy occasionally expressed himself in verse, and communing with these great Frenchmen surely strengthened the conviction that found expression in lines of his which embody a metallurgical simile, and run as follows:—

"If matter cannot be destroyed,
The living mind can never die.
If e'en creative when alloyed,
How sure its immortality."

Gay Lussac, Thénard, Laurent, and Le Play were personally known to Dr. Percy, my predecessor in the chair at the Royal School of Mines. Of the two first-named he writes in 1864, "Both are in their graves, and both bequeathed to France a legacy of fame of which she may well be proud. . . . Laurent also is dead, Le Play survives." Of Le Play, may not we who have seen the glorious Exhibition of 1900 remember how much this great metallurgist did in organising the Exhibitions held in Paris in 1855 and in 1867, at the latter of which he was Commissaire Générale.

The names of two more illustrious Frenchmen to which I would refer in this introduction are those of men who were personally known to some of us, and they connect us directly with the past. These are Jean Baptiste Dumas and Henri Saint-Claire Deville. Dumas was born in the year 1800, and stands first among the chemists of the nineteenth century. When I first met him in 1870, he was Director of the Mint, and it would be difficult to say whether his distinguished manner owed more to gravity or to benignity, outward signs of the qualities of his heart which at once inspired respect and affection. I ask you to join in my tribute to his memory mainly because he represents a grand feature in French science, the union of theory and practice. He illuminated every elaborate research he undertook with the penetration of an inventive genius, and yet turned again and again to the consideration of industrial problems. Recognising their vast importance to the nation, he founded the École Centrale des Arts et Manufactures, where M. Jordan was professor until his lamented death in the present year deprived us of a distinguished member. Among those who have gone the only other memory on which I will dwell is that of Henri Saint-Claire Deville. Reference will be made to his work later on, and beyond offering these few words of personal tribute, I will only add that no man ever had more devoted followers. I am proud to have been one of those who were admitted to the charming gatherings in the laboratory of this gentle master, a laboratory in which all sorts and conditions of men met together, and where, as Dumas said, "chacun se plaisait dans ce milieu sans pretention, ouvert à toutes les hardiesses, fermé à toutes les idées fausses."

As regards the future, judging from experience in the past, the alloys now in use will probably give place to others, and interest will be concentrated not so much on the metals of the nineteenth century as on the men who enabled so much to be done with them. Any information respecting our great leaders will, therefore, be eagerly sought for. You may, nevertheless, have wondered that in an address devoted to iron and steel I should have dwelt so long on these few names, but the earlier chemists of the nineteenth century, like those of the ninth, were often metallurgists. There was no sharp line between chemical science and the metallurgic art which needed the recognition of what are now known to be fundamental principles before it could make progress. You may think it stranger still that I should offer even the slender evidence I have as to the literary union of France and England. My answer is, that the culture of a nation should advance with its industrial progress, and the claims of literature are far too often neglected in relation to those of science. The attributes of iron and steel have, moreover, occupied a prominent place in the literature of our countries. They inspired Ruskin's despondent statement in the "Crown of Wild Olive," that we "have at present in England only one art of any consequence—that is, iron-making," and he adds, with reference to the manufacture of armour-plate, "Do you think on those plates your courage and endurance are not written for ever, not merely with an iron pen, but on iron parchment?" I quoted this sentence to my friend Osmond, and he at once capped it by the lines of Ronsard, who wrote in the sixteenth century—

> ". . . Je veux au mond publier,
> D'une plume de fer sur un papier d'acier,"—

lines which we both claimed as a poetic anticipation of the allotropy of iron, the pen being of harder iron than the steel on which it wrote.

If further justification is demanded, I would plead, in these days when due allowance is made for the influence of environment, that this address was writen in the Mint, in full view of the one building in London which, more than any other, specially reminds us of France—the Tower of William the Norman. The turret is before me in which I like to think that, in the fourteenth century, the erratic pupil of Arnaud de Villeneuve, Raymond Lully, worked. French names, moreover, are in constant use in conducting our daily operations of coinage. We in the Mint consult almost hourly tables calculated by Gay Lussac, and the "Traité des Essais" of Berthier, whose other writings are still my text-books.

The new century was not three years old when communications of the utmost importance appeared in each of our respective countries. In France, in 1803, Claude Louis Berthollet published his brilliant "Essai de Statique Chimique," and in England, Dalton, in the same year, gave to the world his atomic hypothesis, which enabled chemistry to be built up upon a new basis. From that time, in all countries, science has advanced more or less on the lines laid down by these great thinkers; that is, the guiding ideas have either had reference to the *mass* of Berthollet or the *atom* of Dalton. We may follow these lines in recording the metallurgical history of the century, but it will be necessary to trace the industrial applications of science by a third line, connected by links with each of the other lines. By dividing the century into periods, it will be possible to follow the direction, or at least to consider the relations, of these lines without confusion. Along Berthollet's line may be ranged all results which involve the action of mass and cannot be attributed to fixed atomic proportions, while, on the other hand, the course indicated by Dalton involves recognition of the atomic constitution of matter.

It must never be forgotten that both our nations had already turned to Sweden, where theory and practice were united, where the reputation of the pure iron of Dannemora was worthy of the teaching of Upsala. In the great university of that city, Bergman, by pointing to carburisation as the fundamental principle on which the metallurgy of iron rests, conferred a gift on science and on industry the value of which France was the first to recognise. The eighteenth century had still some years to run when Vandermond, Berthollet, and Monge showed the real bearing of Bergman's work in a report, published soon after his death, in which they bear tribute to him as a grand chemist whom the world had lost too soon. In 1806 we find a fundamental statement by Berthollet's countryman and courteous opponent, Proust, which is of singular interest to us. At that early date he describes cast iron as a solution of carbide of iron in iron. He cites it as a case of a compound united to an excess of one of its elements, and clearly anticipates the modern view that carburised irons are solidified solutions in words which are so interesting that they may be quoted at length. He writes: "Mais si nous continuons pour le moment de prendre le carbure de fer pour une combinaison réelle, on conviendra que son existence ou sa dissolution dans les fontes, nous offre l'example d'une combinaison uni à l'excès de l'un de ces élémens." It was in France, moreover, that the evidence as to the carburisation of iron was completed by Clouet's fusion of iron and the diamond; and when, in 1815, Pepys in England, using electricity as a source of heat, removed the last shade of doubt as to the possible influence of furnace gases, the full importance of Clouet's experiment was revealed.

Then came the attack of three great problems—the explanation of the "reduction of metallic oxides" and "oxidation" of metals, and questions connected with the specific heat of metals. These must be taken separately, although our knowledge respecting them was developed concurrently through a long series of years. One of Lavoisier's many claims to our gratitude consists in his having enabled oxidising as well as reducing actions to be clearly understood; hence it became possible to carburise and decarburise iron intelligently, and technology was no longer guided by empiricism but by accurate knowledge. As regards reduction, Lavoisier had recognised that the action of carbon on a metallic oxide was a mutual one; and, as he said, this observation leads us universally to very important reflections on the use of carbon in the reduction of metals. About the year 1814 Foucroy and Vauquelin concisely summed up what was then known by the statement that the removal of oxygen from burnt metals by carbon gave the metals "a new existence." The further explanation of reduction we owe to the classical discussion between Le Play and Laurent, on the one hand, and Gay Lussac on the other, which in the end showed that the reduction of oxides may, according to the nature of the oxide and the conditions under which the operation is conducted, be effected either by carbon or by carbonic oxide.

So far the advance was made rather on the lines of Berthollet than that of Dalton; but in 1819 Dulong and Petit announced before the Academy of Sciences their celebrated law in these words: "Les atoms de tous les corps simples ont exactement la même capacité pour la chaleur." This was widely acclaimed; it was a triumph from the point of view that matter has an atomic structure; it seemed, as has been finely said, that Dulong and Petit, by connecting the fundamental properties of ponderable matter with those of heat, an imponderable fluid or a force, seemed to give the old Greek atomism a modern and higher consecration. The century had, however, not run half its course before Regnault, by a masterly series of experiments, traced the conditions under which alone this law, and certain other laws, hold good. On the results of Regnault's experiments depends the correct appreciation of the efficiency of every engine, whether driven by steam or, as at the end of the century, by "waste" gases of the blast-furnace. At the beginning of the century six lbs. of coal per hour were required to produce one horse-power in a steam-engine; now one-fourth of the above amount is sufficient—a result to which Regnault has in no small measure contributed. We can realise what this means in these days of the still thriftless use of coal, the great source of our industrial wealth. His calculations are of service in connection with every method or process in which the use of gas or heated air is involved, whether it be the estimation of the calorific power of fuel or of the efficiency of the hot-blast stove. So entirely was the importance of Regnault's work recognised, that our elder sister, the Institution of Civil Engineers, voted, in the troubled days of 1848, a sum towards defraying the cost of his research;* but the honour of participation was denied to us, though the intention was greatly appreciated in France, and we must be content to remember that our Royal Society awarded Regnault the Copley Medal, the highest honour it has to bestow.

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* See Appendix at the end of the Address.

I will now turn to the industrial aspect of the metallurgical advance made in France in the first quarter of the century. When the century opened, the production of pig iron in France and in Great Britain showed less disparity than in later years. In the year 1801 the 420 charcoal blast-furnaces in France produced 112,000 tons of pig iron, while the out-turn in our own country was only 200,000 tons. As regards the question of the utilisation of the waste gases of blast-furnaces, which is now deriving great importance from their use in gas-engines, France took the lead. So far as I can ascertain, and Berthier is my authority, in the year 1811 Aubertot made a successful effort to utilise the waste gases of blast-furnaces in his works, which were situated in the Department of Cher. With singular generosity he placed the information he possessed at the disposal of his brother ironmasters, retaining only for his own exclusive use the application of waste gases to the heating of cementation furnaces. It was not until much later that blast-furnace gases were utilised in our own country, and Aubertot was certainly the pioneer. In 1814 England made an industrial offering to France by lending her James Jackson of Birmingham, who at the invitation of the Minister Chaptal occupied a forge at Trablaine in the commune of Feugerolles, and, establishing a cementation furnace, made, by the year 1816, 100 tons of crucible steel. In France the manufacture of "natural" steel obtained by the refining process under Beaunier, and by puddling with the modifications introduced in England by S. B. Rogers, attained great perfection under De Gallois, who established in 1830 near to Saint-Chamond the first English forge on the Loire. De Gallois also set up blast-furnaces, the precursor of which had been the blast-furnace established in 1782 at Le Creusot by William Wilkinson. At Janon, near Terre-Noire, a new era for French blast-furnaces was inaugurated in 1821, and in 1830 at Janon the waste gases from blast-furnaces were used for heating the blast. This was a noteworthy step in advance, but in the use of waste gases from the blast-furnace, France had, as has been already stated, taken the lead. In 1820 MM. Boiguer and Dufand at Fourchambault, and M. François de Wendel at Hayange, had built extensive works which served as models for others. I need not remind you that his distinguished successor, M. Henri de Wendel, is our Bessemer Medallist this year.

As an indication of the progress which French metallurgy had made, it may be added that in the Exhibition of 1834, MM. Jackson Frères, the sons of William Jackson, exhibited an ingot of cast steel weighing nearly half a ton. Seventeen years later, at our own Exhibition of 1851, our heaviest steel mass was only a ton and a quarter, though Krupp showed an ingot of double the weight.

The London Exhibition of 1851 fittingly begins the second half of the nineteenth century.

The first halting-place in physical work must be made at the splendid calorimetric researches conducted in the fifties by Favre and Silbermann, to whom and to Andrews of Belfast we are indebted for the most trustworthy work on the subject. Then came a glorious period of French science, which the work of Henri Saint-Claire Deville adorned. Had he left nothing else than his researches on Dissociation, he would have more than earned our homage in connection with the metallurgy of iron and steel. By bringing into line chemical dissociation and evaporation, and chemical decomposition and ebullition, the researches of Deville gave the views of Isaac Newton on chemical action, so long misunderstood, the most startling confirmation. In France, the country of so many great metallurgists, the school of Deville has done admirable service, not only in developing his work, but in bringing the results of his labours and teaching within the range of practical men.

Every ironmaster now knows how important in the practice of the metallurgic art, and especially in connection with the blast-furnace, are the incomplete chemical processes which tend to re-form the identical substances with which a given operation started. The result of such opposed processes is the state of chemical equilibrium in which both the original and the newly formed substances are present in definite proportions, which remain unaltered so long as the conditions, more especially as to temperature and pressure, remain unchanged.

The discovery of such incomplete reactions is one of the splendid gifts of France to the world. Berthollet recorded their existence at the beginning of the century in the famous "Essai sur Statique Chimique," to which I have referred. Dumas was the first to announce with precision the fact that these limited and opposed reactions set up a condition of equilibrium, and Berthelot and Péan de Saint-Gilles in 1862 established their existence by accurate experiment. It was Henri Saint-Claire Deville who in 1864 realised their wide-spread dominance, and it was the members of the school of Deville who gave an impulse to the promulgation of their master's views. The names of the brilliant members of this school are well known. They are Debray, Troost and Hautefeuille, Isambert, Lemoine, Ditte, and Mouret. Other names might have been mentioned, but the one on which I would dwell is that of Henri Le Chatelier, who by the masterly and authoritative statements contained in his "Recherches Experimentales et Théoriques sur les Equilibres Chimiques," and by his studies in solution applied to salts and to alloys, has firmly established his place among the great physicists of France.

As regards one of the great processes of the century, the name of Sir Henry Bessemer suggests memories of close association with France. We claim his process as one of the greatest achievements in the annals of British metallurgy, and we recall with pleasure how much Bessemer owed to the encouragement received from the Emperor Napoleon III. The necessity for improving the quality of steel arose out of some experiments in gunnery which Bessemer made at Vincennes. As is well known, his process was given to the world in 1856, and the Paris Exhibition of 1867 showed how much progress had then been made. It is to M. de Billy, a member of the metallurgical jury of that Exhibition, that we owe an elaborate and appreciative report, and he was among the first to recognise that the process was the most remarkable of modern metallurgy, for it certainly introduced a true revolution in industrial practice. The application of the Bessemer process to phosphoric iron, which enormously extended its usefulness, was, as is well known, effected in England by Thomas and Gilchrist. The pioneer work of Snelus, also, is too well known to need more than mention here. I would, however, remind you that a correct appreciation of the conditions under which dephosphorisation could be effected was not wanting in France, and in this connection the name of Gruner comes prominently to the front. He pointed, in 1875, to the efficacy of dolomite and bauxite bricks in retaining phosphoric acid, and therefore in purifying phosphoric pig iron, and he seems to have had a clear prevision of the practical solution of the problem which was so soon to be effected by Thomas and Gilchrist in our own country.

Turning to the great rival of the Bessemer process, we clearly see in the efforts which have led to the use of the open-hearth furnace in the manufacture of steel that the union of our national efforts is again conspicuous. As regards the great principle of regeneration as applied to furnace work, we claim its inception by Robert Stirling in 1817. Its development affords the most brilliant instance of the application of science to industry which the latter half of the century has witnessed. It is in no small measure due to the efforts of the eminent French metallurgist, M. Le Chatelier, Inspecteur-Général des Mines, that the open-hearth furnace was introduced into France, and at his instance Sir W. Siemens granted a licence to the Société Boigues Rambourg et Cie. of Fourchambault. It was, however, in the hands of Messrs. Pierre and Emile Martin of Sireuil that the manufacture of steel passed beyond the experimental stage. They did not merely melt steel, but manufactured it on the lines indicated by Réaumur in 1722. Siemens himself worked with the "pig and iron ore" process, and his name is associated with that of Martin in the development of the "scrap" process. For the later results, I will only refer you to the magnificent exhibits in the French section of the Exhibition, where you will see triumphs which have elicited homage from the metallurgists of all nations. It is claimed that it was the great works of Firminy that showed the great part that the process was destined to play by demonstrating that steel of definite and very varied qualities could be obtained with certainty by its aid. There can be no doubt that the publications of Euverte, which were the results of numerous experiments made at the Terre-Noire works, greatly accelerated progress in the use of open-hearth metal.

This brings me to a stage at which we may briefly review the achievements of the modern leaders of our great industry. Metallurgy had, in fact, been gradually increasing her demands on scientific investigators, who were in turn attracted to her service, not merely by the splendid rewards she offered, but by the interest of the problems presented to them. Three periods, which for the purpose of description may be considered to be decennial, separated the Universal Exhibitions which were successively held in Paris in 1855, 1867, 1878, and 1889. The progress made in each of these respective periods has been indicated by the three words, "novelty," "quantity," and "quality." In attempting to characterise the progress revealed in the present Exhibition by a single expression corresponding to the above, I would choose the word "intensity." In 1855 the metallurgy of iron and steel was almost stationary. The time-honoured processes were known to be inadequate, and technical workers were eagerly seeking fresh guidance. Twelve years elapsed, and the results of new efforts were revealed in the Exhibition of 1867, to which the labours of Bessemer, Martin, Siemens, Cowper, Whitwell, and Armstrong contributed so much, and in such original ways, to the general advance.

This was essentially the period of novelty. Eleven years elapsed, the Exhibition of 1878 showed the extraordinary development the new processes had attained, and this was the period in which the quantity of the new products was so remarkable. Then came the period during which the quality of material improved, and the metallurgical exhibits in the Paris Exhibition of 1889 made it abundantly evident that the quality of steel, which was originally considered to be a treacherous material, had attained a high point of perfection. New properties were developed in steel by the addition of such elements as silicon, and more especially by the rarer metals, manganese, chromium, tungsten, and later nickel. The result was that varieties of steel possessing distinct qualities were adapted to a wide range of application. Some kinds of steel were characterised by extreme hardness, while others were very soft; some were magnetic, in others the magnetic permeability was low; some varieties would harden by rapid, and others by slow cooling; certain kinds would even contract when heated and expand when cooled. In all cases the importance of submitting the materials which possess such strange and novel qualities to suitable thermal treatment became evident. In this way the period between 1889 and 1900 is reached, and this period I have already characterised by the word "intensity." No process of marked novelty has been devised, though there have been modifications and developments of the existing processes, and the scale on which they are conducted has been greatly increased. The investigators have in many cases been the same as in the preceding decade, but there has been intensity of aim and concentration of effort in bringing physical methods, and the results of investigation in pure science generally, into line with industrial requirements. In effecting this our two countries have worked in unison. Progress has been made mainly in two directions:—

1st. The preparation of new alloys of iron.

2nd. The study of the properties of iron and its alloys.

Alloys of iron and chromium present a remarkable instance. Berthier prepared the first alloy of chromium and iron in 1820, and Boussingault also devoted some attention to them. Brustlein had manufactured these alloys in the works of Jacob Holtzer, since the year 1877; but the Exhibition of 1889 first made us familiar with rich alloys containing 84 per cent. of chromium. In 1900 we find Brustlein renewing his efforts, and we are glad to welcome him on the jury of the metallurgical class. Chrome steels have passed beyond the crucible stage, and are prepared on the open-hearth with 3 per cent. of chromium, as is also a triple alloy of iron, chromium, and nickel for use as armour-plate and in artillery. As regards our English efforts, we all know how much Hadfield has done in extending the use of iron and chromium alloys for projectiles. At about the same time that Berthier gave us the first alloy of iron and chromium, Faraday prepared the first specimen of an alloy of iron and nickel, the future of which has proved to be so great. In the year 1884 M. Marbeau of the Société Ferro-Nickel produced their first alloys either in Paris or at the works at Lizy-sur-Ourcq, while at the Paris Exhibition of 1889 the Société showed the first alloys of iron with varying proportions of nickel. The Journal of our Institute for the year 1889 contains a paper by James Riley, "On the Alloys of Nickel and Steel," which will be familiar to all of us. In France, at Montataire and at Imphy, attempts were also made to prepare alloys of iron and nickel, while at Le Creusot in 1888 a systematic study was made by M. Werth of the alloys of nickel with iron and with steel, a study which he continued at Fourchambault and at Imphy, obtaining results of practical importance. The manufacture of nickel steel in the open-hearth furnace was undertaken at Le Creusot, and in 1900 trials made at Annapolis on an armour-plate manufactured by Messrs. Schneider & Co. revealed the remarkable properties of the variety of nickel steel which contains five per cent. of nickel. Since that time the manufacture of nickel steel in France has, as the contents of the Exhibition abundantly prove, assumed much importance, a result which is mainly due to the work of M. Werth. In the past decade it may well be claimed, therefore, that the efforts to employ nickel steel have been intensified.

I have not referred in this brief summary to the other elements which are present simultaneously with nickel. I need only appeal to results shown in the present Exhibition as indicating the way in which efforts to apply nickel steel have been intensified.

As regards the alloys of iron and manganese, the English name of Josiah Marshal Heath will be familiar to you all. A French engineer, M. F. Valton, director of the Terre-Noire Steelworks, was, however, among the earliest to give an explanation of the part manganese played as a deoxidiser in the final stage of the Bessemer process. I need not remind you that in 1876 M. Gautier made an important communication to our Institute on ferro-manganese, the use of which greatly contributed to the success of the manufacture of steel in the open-hearth furnace, and in 1868 Siemens called attention to the peculiar action of manganese on steel, and pointed to the influence of silicon in enabling sound castings to be produced. In 1875 M. Pourcel undertook the manufacture of ferro-manganese in the blast-furnace. In the same year M. Muss of the Châtillon Commentry Company, and M. Jordan of the Saint-Louis Works, also took the manufacture in hand. Progress in this direction was rapid in France, and we all know how much our late and deeply lamented member, M. Jordan, did for this great branch of manufacture. The magnificent exhibits of iron-manganese alloys in the present Exhibition testify to the increased importance of the work which M. Jordan so recently directed. In England ferro-manganese was produced at the Pyle and Blaina Works, at Mostyn, at Darwin, at Wigan, and at the works of Messrs. Bolckow, Vaughan, & Co. At the time of the former Exhibition in Paris, 1889, England was the dominant user.

I need not remind you that Hadfield, about the time of the former Exhibition in Paris, astonished the metallurgical world by producing steel containing from 7 to 21 per cent. of manganese, and possessing remarkable properties. His later work on the same alloys has only served to intensify interest in his earlier investigations, and it affords another instance of the renewed efforts which characterise the last decade. I will not weary you by passing in review the other alloys of iron, such as those with silicon, tungsten, and titanium; but I must not omit reference to the researches of MM. Moissan and Charpy on boron steel, of which we shall hope to hear much more in the future. May we not hope that in the next century vanadium, uranium, molybdenum, and even glucinum, will prove as faithful allies as certain of the better-known metals have been.

The second direction in which efforts have been intensified is in the study of the properties of iron and its alloys. The investigations may be conveniently divided thus:—

a. Those which relate to the physical properties of iron and its alloys, as revealed by thermal measurement.

b. Those which have for their object the study of the structure of iron, and the grouping of the constituents in its alloys as revealed by the microscope.

The work that may be ranged in both of these groups had an earlier origin than is quite realised at the present day. As regards pyrometry, which occupies a prominent place in the first group, space absolutely forbids my attempting to give a history of the blended efforts of our two countries, and I must only permit myself to recall a few of the more prominent names, and not pass beyond the limits of the present century. Guyton de Morveau in 1808 fully recognised the value of the early pyrometric efforts of Wedgwood. Magnificent work with the air thermometer has been done by Saint-Claire Deville and his school, and the work may be traced back to Princep and to the distinguished Frenchman, Pouillet. As regards the two methods which are now employed, the initiation of the use of thermo-couples is entirely French. The work began with Antoine Cæsar Becquerel, and was continued by Pouillet and by Edouard Becquerel. On the other hand, Siemens, in England, was the first to demonstrate the eminently practical nature of the pyrometric method, which depends on variations in electrical resistance, a method which was destined to be perfected and extended by Callendar and by Griffiths.

If, however, we turn again to France, we find Henri Le Chatelier completely changing all the details of pyrometric work that involved the use of thermo-couples, and his success is the more remarkable, as Regnault greatly discouraged experimenters by stating that he saw little that was hopeful in the prospect of the use of thermo-couples. Le Chatelier has thus conferred a debt of gratitude on industry which it will be difficult to adequately acknowledge. At the time of the Paris Exhibition of 1889 the value of the Le Chatelier pyrometer was beginning to be recognised by industrial workers; but the next step was made in England, when, in 1892, a recording pyrometer with a thermo-couple was first introduced into the Dowlais Works. It is now evident, as the result of efforts made in both countries, that all delicate operations, such as quenching steel gun-tubes and rolling armour-plate, and all operations in which changes of vital importance take place within a narrow range of temperature, must be controlled by careful pyrometric observations. I hope it will ultimately be seen that the work entrusted to me by the Alloys Research Committee of the Institution of Mechanical Engineers has shown our national co-operation with France in the solution of the great problems connected with the constitution and properties of steel.

The century opened with the expression of fundamental but comparatively simple views as to the constitution of steel. The importance of carburisation had been accepted and the protean nature of iron itself had been recognised in Bergman's classical phrase, "*polymorphum ferrum.*" As the century closes it is seen that iron has gathered to itself, often in considerable volume, numerous associates with which it was originally entrusted only in small quantities. Industry has consequently been enriched by varieties of metal possessing properties hitherto unknown. These properties have been investigated by a host of workers, and the mention of only a few names may seem to be invidious. Nevertheless, I am satisfied that when writers come to look back to the end of this century, as we do to its beginning, the phenomena connected with iron and steel to which they will revert will be comprised in the words "points of transformation." Our country will receive its share of these retrospective thoughts, for the names of Gore and Barrett are waymarks. Tchernoff will be remembered, for he proposed a thermometric scale by which manufacture of steel could be controlled.

From among Frenchmen one name will arise in the memories of future historians of metallurgy, and that name will be Osmond. It will not be forgotten how much Osmond did in defining the modes of existence of carbon in steel. It will be remembered that by his observations a single point of recalescence became resolved into many points. He traced the influence of hysteresis, and showed how the position of the points of transformation vary, within a certain range of temperature, with the element with which the iron is allied. He showed that if a certain variety of steel has been quenched at a point above or below its critical point, it may present one or other of two states of equilibrium. These may be widely different, either as a consequence of change either in the allotropic state of one of the constituents or in the chemical grouping at the moment the metal passes the critical point. I am not unmindful that M. Grignon, who translated Bergman's "De Analysi Ferri" into French, shared his views as to the allotropy of iron, nor do I forget that Cizancourt pronounced advanced views on the subject in 1865, as did also Tait in the Rede Lecture delivered at Cambridge in 1873. Osmond, in fact, insisted on the allotropy of iron, proved its fundamental importance, and identified himself with its study, but that, though it is his great achievement, is far from being his only one. He showed that the properties of steel are a function of the cycle of temperatures to which it has been subjected. There have been many workers whose investigations possess strong individuality and significance peculiarly their own whose results nevertheless intensify the interest of Osmond's labours and conclusions. I hope I may be forgiven the brevity with which I cite these. Pionchon showed that at a temperature of 700° the specific heat of iron is altogether exceptional. Guillaume studied a series of nickel steels in which the transformations are reversible. This reversibility is associated with some important peculiarities as regards expansibility. Henri Le Chatelier pointed to magnetic irreversibility in the case of certain manganese steels. He moreover examined the influence of the gaseous atmosphere surrounding the steel in which the points of transformation occur. Charpy studied the hardening of steel with reference to the critical points. Tomlinson showed that the molecular change in iron is revealed by a change in magnetic properties. Madame Curie showed that the allotropic change effects a true magnetic transformation. Dumont recently pointed out that in nickel steel the point at which magnetic transformation occurs depends on the proportion of nickel present, while experiments by Guillaume and by Dumont indicate that chromium acts like carbon on certain irreversible varieties of steel and lowers the temperature at which magnetic transformation occurs. Carnot and Goutal isolate various compounds which in special varieties of steel give rise to variations of properties. The great importance of critical points in relation to the dimension of grain in steel, and consequently to its strength and extensibility, has been shown by Brinell, by Sauveur, and by Morse.

The second group into which modern investigation may be divided involves the use of the microscope, and the application of this instrument to the metallurgy of iron is less recent than it is often supposed to be. Réaumur in 1722 describes the structure of a chilled casting under the microscope, and traces the changes in the structure of softened cast iron as modified by the elimination of impurities. François, again, so early as 1833, took the very interesting case of the direct reduction of iron from its ores, and followed the successive changes by the aid of the microscope. The following passage, translated from this quaint and accurate observer, is full of interest, and might almost have been written by any of us to-day:—

"If to these analytical data observations under the microscope with a magnification of 300 to 400 diameters be added, it is seen that ordinary iron is merely a metallic network with a close-grained tissue with submerged scoriaceous opaline, sometimes subcrystalline, portions, and with little globules and metallic grains ranged in every direction. Sometimes nests of translucent prismatic and bacillary crystals, with metallic portions adhering, are noticed hidden in the paste. These are the grains of steel which can be made to disappear by heating."

England in turn in 1864 gave a new impetus to this important branch of investigation by the labours of Sorby, in whose admirable work polished and etched sections were employed. The microscope as an implement of research hardly received due recognition until Osmond published a classical series of researches which have earned the lasting gratitude of investigators. In no branch of my subject do I so much regret that the limitations of space have obliged me to confine myself to the bounds of our two countries, as I should like to have dwelt on the micrographic work of Martens, Sauveur, Behrens, and many others. I will only add that the work of Stead deserves special recognition, not only for its minute accuracy, but for its originality. Quite recently Ewing and Rosenhain have obtained most interesting results, which go far to explain by micrographic evidence the elasticity and flow of metals, and also the mode by which crystals grow in metallic masses.

A Report of the Departmental Committee on Steel Rails recently issued is the first Government publication in England in which the importance of micrography has been recognised.

Scientific discoveries have during the century worked a complete change in our intellectual appreciation of natural phenomena, but in our work the standpoint of the new century will be singularly like that of the old. A few tenths per cent. of carbon hidden in iron still dominates our branch of metallurgy. Bergman recognised this before the nineteenth century began, and insisted both on the polymorphy of iron and the importance of carbon in relation to it. He pointed out, moreover, that in every great change effected in the constitution of iron, heat is either absorbed or evolved. The sentence in which Bergman sums up the results of his own calorimetric experiments is full of interest:—"Si præcedentis momenti allata experimenta considerantur, haud difficulter elucet, quemlibet statum respectu caloris absconditi circumscriptum esse."

Allotropy and carburisation of iron will be the first passwords of the twentieth century, and Osmond, the great allotropist of the age, has blended their significance by showing that the power iron has to retain carbon in solid solution depends on the particular allotropic form in which the iron exists. There is no other fact which so profoundly affects the industry of the world.

We now know, but only at the end of the century, that in steel of somewhat low carburisation, but wide industrial application, the heat equivalent of the allotropic change is exactly double that due to the change of the relation between the carbon and the iron, the respective figures being 18 and 9 calories.

As one of the last important engineering works in a century which the Eiffel Tower would alone have made remarkable, I may refer to the Alexander III. Bridge, a great structure in which a different material is used from that employed by M. Eiffel. It crosses the Seine in a single span, and 2200 tons of cast steel have been employed in its construction. If the steel used in such a structure is heated to a temperature of 1000° and is "quenched" by rapid cooling in air to about 600°, the metal so treated becomes stronger, more elastic, and resists shock better than if it had been annealed. Hence the material adopted in this great work of the very able engineers, MM. Résal and Alby, which so intimately expresses the genius of the Exhibition of 1900, affords the last cognate illustration of the importance and accuracy of Osmond's views.

I must not omit some reference, though it must necessarily be brief, to the metallurgical literature of our two countries. This has been greatly enriched by the admirable treatise on "Metallurgy" written by Dr. John Percy, which developed into a series of volumes, containing no less than 3500 octavo pages, the last of the series appearing in 1880. He was, it will be remembered, President of this Institute during the years 1885–87. His volumes are remarkable throughout for minute accuracy, and for the care with which the illustrations were prepared, almost every woodcut being a trustworthy though small measurable drawing. He has given us, in terse and vigorous English, a priceless record of many early processes, and ones which, though later, are obsolete. He was firmly impressed with the fact that metallurgical problems demand for their investigation the exercise of the highest analytical skill, and involve considerations worthy of those who delight in transcendental inquiries. He effectively quotes Réaumur's remark, "L'utile bien considéré a toujours du curieux, et il est rare que le curieux bien suivi ne mène pas à l'utile." I have elsewhere observed that he studied in Paris, making the acquaintance of the leading French chemists of the time, who doubtless directed him towards the line of work to which his life was mainly devoted. Percy may fairly be said to have originated the English literature of metallurgy, for until his time the works on metallurgy were slender and far between. This was not the case in France, where the works of Rivot, the admirable and profusely illustrated treatises of Jordan, as well as those of the great chemists I have named earlier in this address, were well known. France, moreover, possessed in the *Annales des Mines* a veritable storehouse of knowledge, which has done for the iron and steel industries throughout the century what our own Journal has attempted to do in the latter half of it. I would only add, that if Percy has been the historian of metallurgy, Gruner systematised it. I would gratefully offer my testimony to the value of his "Traité de Métallurgie" as a model of scientific exposition and methodical criticism which enabled the tangled threads of metallurgical practice to be unravelled. Few men have more effectively combated than he did the assumption of prejudice and mystery which all branches of the metallurgic art too long retained.

There are many subjects you will regret that I have not touched upon. The question of naval defensive armour, for instance, might well have been referred to even on so eminently pacific an occasion as the last Exhibition of the century, but I will content myself with reminding you that France was the pioneer in the employment of naval armour, and that the launching of the armour-protected *La Gloire* in 1860 gave the signal for the reconstruction of European navies.

The extraordinary development of the use of iron for constructive purposes revealed by the present Exhibition, demands that some reference should be made to the relations of iron and steel to art, with which industry and science are so closely connected.

> "And trade is art, and art philosophy,
> In Paris,"

as Mrs. Browning reminded us. The vast array of ephemeral buildings which line the Seine has been compared collectively to a huge organism, the bones and fibres of which are of iron and steel, covered with an investing body of plaster that has served as a basis for adornment of all kinds. There are some who doubt whether, from an architectural point of view, the lavish use of the new resources which metallurgists have afforded has been successful. A subtle critic, M. Robert de la Sizeranne, in a brilliant paper recently published, entitled, "L'Esthétique du Fer," takes a despondent view of the result, and considers this new use of iron to be "à la fois le triomphe du progrès scientifique et son châtiment." But when he turns to the beautiful bridge, which, as I have already said, is an exponent of the genius of the Exhibition, he writes enthusiastic words, which I may well quote, and are as follows:—"Nous ne quitterons pas les bords du fleuve sans avoir senti la vie. Car elle est dans ces formes admirables du pont Alexander III. Ceci aussi c'est de l'art."

For my own part, being a metallurgist, I cannot expect that any importance will be attached to my individual opinion on an æsthetic question, but I would venture to observe that ideas of beauty are instinctive, and that pleasure in the contemplation of any work, whether of nature or art, depends on delicate and untraceable perceptions of fitness, propriety, and relation. This being admitted, I find myself unable to stand under the Eiffel Tower, and follow the course of the curved lines, which suggest the details of an immense but delicate coral, without being carried away by the impression that the structure is not only wonderful but beautiful.

The part played in the industrial evolution of the world by iron and steel metallurgists will be evident to all. The fact that they have contributed with commensurate success to the advancement of pure science is less generally known, and I may well, therefore, devote a few words in conclusion to recording some instances which readily present themselves. The carburisation of iron offers the first case in which the diffusion of solids in solids was observed. The study by metallurgists of the associations of carbon and iron has elucidated the most complicated case yet known, and indeed the only one which has been worked out, of metallic solid solutions. It presents, moreover, a unique case of the importance of allotropy in connection with metals. In 1000 parts of steel, 997 parts, more or less, may be iron and the rest carbon, but the result of the union is a metal that is more widely used and has more varied attributes than any other. It would seem that nature has enshrined in steel a series of her most complex secrets which we must discover as a condition of our successful use of it. Metallurgists have carefully investigated, and conduct daily, operations of vast industrial importance, in which the presence of a third body enables either elementary bodies or compounds to react on each other. By habitually conducting operations at high temperatures, which often invert ordinary chemical reactions, the metallurgist has acquired a mass of information as to the reactions that do occur, and the compounds that are formed under such conditions. Pyrometric records have, moreover, enabled the equilibrium of the less fusible metals in their liquid as well as in their solid state to be studied —a branch of work which chemists generally have not been in a position to undertake. The necessity for submitting the physical and mechanical properties of iron and its alloys to rigorous tests, as a routine operation in Works, has afforded a rich store of information as to the molecular constitution, not only of metals, but of matter generally. Metallurgists have to deal with cases in which a mass of metal is acted upon by added matter in proportions that are too minute to intervene directly by the formation of chemical compounds with the whole of the mass, while in some cases no compounds are formed. The influence of the atom must, therefore, be more or less directly exerted. Hence it is that we, who still conduct processes, the traditions of which came down to us from mythological times, have done our share in "giving the old Greek atomism a modern and a higher consecration."

We hold this meeting as the representatives of the greatest industry the world has seen. We are more than this, for we are the exponents of the scientific and industrial union which subsists between our nations, and of the national appreciation that has remained unabated though tumults have shaken our peoples. May both nations in the coming century not forget how much we owe to the old Greek guidance. The Greeks gave us the name Siderurgy, by which our art is known in France. Plato, moreover, told us that the god who moved men through their sympathies inspired the invention of all industrial art, "the melody of the Muses, the metallurgy of Hephæstus, the weaving of Athene;" and if you have followed this brief address, you will realise how much metallurgical progress has owed to sympathy—the great interpreter which joins the industrial workers of France and England in a bond of peace that is stronger than iron, truer than steel, and yet is one which is sufficiently extensible to embrace all our peoples.

APPENDIX

The statement as to a vote in the troubled days of 1848 of a sum towards defraying the cost of Regnault's research was made on the authority of M. J. B. Dumas, who, in his charming *éloge* of Victor Regnault (*Discours et Eloges Académiques*. Paris: Gauthier Villars, tome ii., 1885), states that the Société des Ingénieurs de Londres, struck by the beauty of Regnault's results, wished to place at his disposal the necessary funds for the continuance of his experiments. He adds (p. 185): "On aime à rapeller ce vote libéral des ingénieurs anglais, constatant une fois de plus que la science appartient au mond civilisé et qu'elle ne connait pas de frontières." Dumas thus definitely alludes to a "vote;" but he was, as it proves, imperfectly acquainted with the circumstances, and I was unable to test the accuracy of his information in time for the delivery of the Address. I have, however, by following an indication given me by my friend, Prof. Henri Le Chatelier, satisfied myself, though with great difficulty, as to the facts. It appears that what M. Dumas believed to be "ce vote libéral des ingénieurs anglais," was really a generous offer of an individual engineer, the late Mr. R. S. Newall, who wished Regnault to accept £500 "to enable him to complete his experiments on steam," as is recorded in a note in Mr. Newall's writing, which Mrs. Newall has most kindly shown me. The offer was not accepted, for the French Government supplied the necessary funds, and, as M. Dumas correctly states, "La France pourvut elle-même à la continuation de l'œuvre commencée et que reste son œuvre." It has seemed to me to be in every way desirable that this interesting episode in international scientific history should be in all respects correctly described, hence the addition of this Appendix.

The following paper was then read:—

THE DEVELOPMENT OF THE IRON INDUSTRY IN FRANCE FROM 1888 TO 1898.*

BY H. PINGET, SECRETARY OF THE COMITÉ DES FORGES DE FRANCE.

IN reference to the expression of a desire by the Council, the author has great pleasure in presenting to the members of the Iron and Steel Institute the following review of the present conditions of the iron industry in France, and of the progress made since their last visit to Paris in 1889. He desires to take this opportunity of thanking the Council for the honour they have done him in entrusting him with the task of preparing these notes. Similar descriptions were given by the late Professor S. Jordan at each of the preceding visits of the Institute to Paris in 1878 and in 1889, and the author would request the indulgence of the members when they compare his work with that of such a distinguished and greatly regretted authority.

A succinct account of the collieries and iron ore mines which supply the raw materials for the iron industry will be given in the first instance, as that seems to be the most logical course to pursue.

COAL.

The following table shows the official statistics of the production of coal in the years 1888 and 1898:—

Coalfields.	1888.	1898.
	Metric Tons.	Metric Tons.
Nord and Pas-de-Calais	12,293,000	19,287,000
Loire	3,185,000	3,912,000
Bourgogne and Nivernais	1,594,000	2,341,000
Gard	1,851,000	1,974,000
Tarn and Aveyron	1,147,000	1,781,000
Centre	951,000	1,123,000
Other basins: Auvergne, Vosges-Meridionales, Alpes-Occidentales, Hérault, Creuse and Corrèze; Ouest, and Corsica	1,151,000	1,408,000
Total coal and anthracite	22,172,000	31,826,000
Lignite	431,000	530,000
Grand total	22,603,000	32,356,000

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* 1898 is the latest year of which the complete and final statistics have been published. The metric ton of 2204·8 lbs. or 0·984 English ton is used in this paper. The figures must therefore be reduced slightly more than 1½ per cent. to obtain English tonnage.

These figures show that the production of mineral fuel has increased 43 per cent. during the period under consideration, and that the increase has chiefly taken place in the coalfields of Nord and Pas-de-Calais, where it represents nearly two-thirds of the total rise. The great activity of the metallurgical industries in these departments during recent years, and the difficulty of obtaining sufficient coke from Germany, have contributed to the development of the production of the local collieries.

All the different coalfields, except two of minor importance, have progressed, but in a very unequal degree, as is shown by the following table:—

	Increase. Per Cent.
Nord and Pas-de-Calais	57
Loire	23
Bourgogne and Nivernais	47
Gard	7
Tarn and Aveyron	55
Centre	18

The next table indicates the source whence the coal consumed in France was derived, and shows that the home production was only about three-quarters of the amount used.

	1888.	1898.
	Metric Tons.	Metric Tons.
Home production	22,122,500	31,378,000
Coal imported from England	4,108,000	5,486,000
Coal imported from other countries	6,443,500	6,431,000
Total imports	10,551,500	11,917,000
Total consumption	32,674,000	43,295,000

Ironworks play a very important part in this consumption. Even omitting the numerous works employed in the further treatment of the metal, in 1898 they used 2,622,000 tons of coal and 3,200,000 tons of coke, or altogether 7,400,000 tons of raw coal besides 16,000 tons of charcoal. This quantity is as much as is used by the collieries and the railways together, so that the combined consumption of those three industries represents more than a third of the total consumption of France.

According to the provisional statistics for last year, 1899, the total production of coal and lignite in France amounted to

32,933,800 metric tons, and the imports to 10,467,400 tons, of which 5,925,000 tons came from England.

IRON ORE.

The iron ores worked in France are divided into five classes, of which the production is given below:—

Kind of Ore.	1888.	1898.
	Metric Tons.	Metric Tons.
Oolitic ore	2,456,000	4,170,000
Limonite	86,000	144,000
Other hydrated ores	106,000	155,000
Hæmatite and specular ore	150,000	208,000
Spathic ore	44,000	54,000
Total	2,842,000	4,731,000
Number of mining concessions at work	64	75
Number of quarries at work—		
Groups	40	46
Centres of working	...	114

The hydrated oolitic ore constitutes the larger proportion, 88 per cent., of the output in 1898. It is chiefly worked in the department of Meurthe-et-Moselle, where 42 mines and 16 mining centres in 1898 produced 3,884,000 tons as compared with 2,261,000 tons in 1888, an increase of 1,625,000 tons or 70 per cent. The ore in this department is worked in two distinct districts, Nancy, 1,673,000 tons, and Longwy, 2,211,000 tons. The more important mines and their outputs in 1898 were as follows:—

In the Nancy district:—Chavigny, 346,000 tons; Val de Fer, 234,000 tons; Ludres, 175,000 tons; Marbache, 134,000 tons; Bouxières-aux-Dames, 111,000 tons; Boudouville, 98,000 tons; Fontaine-des-Roches, 95,000 tons.

In the Longwy district:—Hussigny, 567,000 tons; Saulnes, 308,000 tons; Moulaine, 239,000 tons; Micheville, 294,000 tons; Godbrange, 242,000 tons; Tiercelet, 150,000 tons; Longlaville, 108,000 tons.

Oolitic ore was also extracted to the extent of 123,000 tons at Vassy in Haute-Marne and of 126,000 tons at the mines of Mazenay and Change in Saône-et-Loire.

Limonite, or ores in which that substance predominates, was produced in the departments of Pyrénées-Orientales (91,000 tons), Ariège, Tarn, and Aveyron.

Hydrated ores which contained limonite in smaller proportions were mainly drawn from Gard, 65,000 tons, Lot-et-Garonne, 24,000 tons, and Cher, 20,000 tons.

Hæmatite was worked in the departments of Calvados, 152,000 tons, and of Ardèche, 54,000 tons. Specular ore came from the Pyrénées-Orientales, which also gave nearly two-thirds of the spathic ore. The remainder was obtained in Isère and Aveyron.

As regards the production of iron ore, the department of Meurthe-et-Moselle is very far in the van, but its position will be still more important in the near future, owing to the development of new concessions in the districts of Briey and Audun-le-Roman to the south of Longwy. A number of bore-holes, started some years ago, have now proved the underground extension of the ore formations which have previously only been worked on the outcrop around Nancy and Longwy. This discovery has led to the application for a number of concessions, of which the latest dates from March 1900, and the total area included covers over 30,000 hectares (74,136 acres). At the present time only two new mines—those at Joeuf and at Homécourt—are at work, but three others are to be started. At Auboué, one of the latter, the shafts, sunk to a depth of 136 metres (148 yards) by the Poetsch freezing process, are now finished.

The amount of ore smelted in France is assumed to be the quantity produced in the country, less the exports and plus the imports, no allowance being made for variation in stocks.

Ores from	1888.	1898.
	Metric Tons.	Metric Tons.
France	2,548,000	4,495,000*
Germany and Luxemburg	835,000	1,411,000
Algeria	25,000	68,000
Spain	387,000	445,000
Other countries	63,000	108,000
Totals	3,858,000	6,527,000

* Including 250,000 tons of cinder and burnt pyrites.

The proportion of foreign ores smelted in the French blast-furnaces has increased by 722,000 tons, or 55 per cent., between 1888 and 1898. The greater part of this increase, amounting to 576,000 tons, is due to the oolitic ores brought from across the German frontier and to the minette ore from Luxemburg. As 90 per cent. of the increase in the home production in France is ore of a similar nature, it follows that the import of rich ores has fallen from 12 to 9 per cent., and that the average yield of the ores charged has decreased from 45 per cent. in 1888 to only 39 per cent. in 1898.

PIG IRON.

The statistics of the production of pig iron in France may be summarised as follows:—

Production of Pig Iron.

	1888. Metric Tons.	1898. Metric Tons.
From coke	1,662,000	2,505,800
From charcoal	12,800	7,500
From mixed charcoal and coke	8,500	11,800
Total	1,683,300	2,525,100

Materials Used.

Coke	1,936,000	3,147,100
Charcoal	...	11,100
Ore	3,858,000	6,527,000

Number of Furnaces in Blast.

Coke	90	101
Charcoal	12	7
Mixed charcoal and coke	4	3
Total	106	111

The total production of pig iron has increased by more than 842,000 tons, or 50 per cent. In view of the small increase of the number of furnaces in blast, which has only reached 5 per cent., and of the diminution in the average yield of the ore charged, the change must be ascribed almost entirely to the increase in the size and power of the plant. As regards pig iron made with coke, the average annual production of each blast-furnace has increased from 18,500 to 24,000 tons. It has attained to 30,000 in the departments of Meurthe-et-Moselle and Nord, and to as much as 40,000 tons in Pas-de-Calais, where the material treated consists almost entirely of Bilbao ores, specular ores from Elba, and the manganiferous ores from the south of Spain, and of which the iron contents are far higher than those of the oolitic ores in the eastern districts.

The average consumption of coke per ton of iron was 1·260 ton in 1898. In 1888 it was only 1·168 ton, and this difference is due to the different quality of the coke and to the lower yield of the ore at the present time.

The manufacture of charcoal iron has become very insignificant. It is carried on in five departments—Charente, Dordogne, Landes, Haute-Marne, and Haute-Saône—simply because of a small demand for special qualities. The same may be said of the iron made with a mixture of charcoal and coke, which is only produced in Cher and Haute-Marne for foundry-work. These two kinds together do not amount to a hundredth part of the total production.

Disregarding the kind of fuel used, the production of iron may be classified according to its intended use as follows:—

	1888.	1898.	Increase.
	Metric Tons.	Metric Tons.	Metric Tons.
Forge iron for puddling and steel-making .	1,306,400	2,018,000	711,600
Foundry iron	313,100	417,100	104,000
Direct castings	63,800	90,000	26,200
Totals . .	1,683,300	2,525,100	841,800

The production of ferro-manganese and other special iron included with the forge iron above, was 10,692 tons in 1898, and was 1140 tons less than in 1888.

Although twenty-two departments were producing pig iron in 1898, only seven had an annual out-turn of over 50,000 tons. The following table shows the production according to the departments classed in groups:—

Groups.	1888.		1898.		Per Cent. of Total Production in 1898..
	Furnaces in Blast.	Production.	Furnaces in Blast.	Production.	
		Metric Tons.		Metric Tons.	
Nord and Pas-de-Calais	12	317,200	12	367,600	14·56
Meurthe-et-Moselle .	36	911,000	53	1,550,600	61·41
Champagne (Haute-Marne, Ardennes, Meuse)	13	68,900	8	44,100	1·74
Franche-Comté (Haute-Saône)	1	1,700	1	200	
Centre (Allier, Cher) .	10	41,000	4	40,500	1·61
North-west (Loire-Inférieure)	1	12,900	2	74,500	2·95
Périgord and Aveyron (Lot-et-Garonne, Aveyron, Dordogne, Charente, Tarn) . .	4	21,300	5	46,700	1·85
Pyrénées and Landes (Ariège, Pyrénées-Orientales, Landes, Gironde)	10	71,000	8	106,400	4·22
Loire and Rhône (Ardèche, Loire, Rhône, Saône-et-Loire) . .	11	157,100	9	169,700	6·72
Alpes (Isère)	3	13,400	3	35,700	1·41
South-east (Gard, Bouches-du-Rhône) . .	5	67,800	6	89,100	3·53
	106	1,683,300	111	2,525,100	100·00

In Meurthe-et-Moselle more than six-tenths of the total was produced in 1898. Last year the total production of pig iron was 2,567,400 tons, of which this department was accountable for 1,564,800 tons.

The different kinds of iron were made in the various districts as shown by the following table, which relates to 1898:—

Groups.	Forge Iron.	Foundry Iron.	Direct Castings.
	Metric Tons.	Metric Tons.	Metric Tons.
Nord and Pas-de-Calais	367,000	...	...
Meurthe-et-Moselle	1,152,500	328,400	69,700
Champagne (Haute-Marne) . . .	24,300	17,300	2,500
Franche-Comté (Haute-Saône) . .	200	...	...
Centre (Allier, Cher)	20,400	14,000	6,200
North-west (Loire-Inférieure) . .	57,100	17,400	...
Perigord and Aveyron (Lot-et-Garonne, Aveyron, Dordogne, Charente, Tarn)	23,200	11,900	11,600
Pyrénées and Landes (Ariège, Landes) .	102,100	4,300	...
Loire and Rhône (Loire, Rhône, Ardèche, Saône-et-Loire)	154,900	14,700	...
Alpes (Isère)	35,700	...	...
South-east (Gard, Bouches-du-Rhône) .	80,000	9,100	...
Totals	2,018,000	417,100	90,000

As regards forge iron, Meurthe-et-Moselle, with its production of 1,152,500 tons, of which 682,300 tons is basic pig, makes 57 per cent. of the total. The departments of Nord and Pas-de-Calais, which constitute the next group in order of importance, are far behind with 367,000 tons. Seventy-nine per cent., or 328,400 tons of the foundry iron, are also produced in Meurthe-et-Moselle, which is followed by Loire-Inférieure and Haute-Marne. None of the other departments produce more than 10,000 tons. For direct castings Meurthe-et-Moselle takes the lead with 69,700 tons, or 77 per cent. of the total.

Nearly the whole (over 99 per cent.) of the direct castings made in France are produced in five works — The Société anonyme des Hauts-Fourneaux et Fonderies de Pont-à-Mousson and the Société anonyme Métallurgique d'Aubrives et Villerupt, both in Meurthe-et-Moselle; the Société Métallurgique du Périgord in Lot-et-Garonne; the works at Montluçon in Allier belonging to the Société anonyme de Commentry-Fourchambault et Decazeville; and the Société anonyme des Hauts-Fourneaux et Fonderies de Brousseval in Haute-Marne.

The department of Meurthe-et-Moselle, where even now the production of pig iron preponderates so greatly, is still on the road to further developments. Its new mineral resources have already been referred to, and now new blast-furnaces have been built, and others, in course of construction, will soon be put in blast. It is in this district that the most modern plants are to be found. Seventeen new furnaces have been erected, and nearly all those which were in existence in 1888 have been reconstructed within the last ten years, together with their hot-blast stoves and blowing-engines, in order to increase their out-turn. The daily production is 160 tons, or even 200 tons in certain furnaces, with ore burdens which do not reach an iron content of 30 per cent.

The use of methods of granulating slag has a tendency to spread, and several works have adopted the manufacture of cement. A start has been made in several of the eastern works with the direct utilisation of blast-furnace gas for the production of power, and a number of gas-engines are at work for the purposes of the transmission of power, lighting, and driving blowing-engines.

Outside this department of Meurthe-et-Moselle the production also shows a tendency towards development on the sea-coast, and new works are being built at Pauillac in Gironde and at Cette in Herault.

The extent of the progress during the period under consideration of the external trade in pig iron is shown by the following figures:—

	1888.	1898.	Increase.
	Metric Tons.	Metric Tons.	Metric Tons.
Imports	126,569	159,000	32,431
Exports	24,540	163,342	138,802

Thus the surplus of imports over exports of 24,540 tons in 1888 was reversed in 1898, when the exports exceeded the imports by more than 4000 tons.

WROUGHT IRON

The official statistics of the wrought iron industry in 1888 and 1898 are as follows:—

	1888.	1898.
Production:—	Metric Tons.	Metric Tons.
Puddled iron	634,400	531,700
Charcoal iron	13,700	6,000
Re-manufactured from old iron and scrap . .	168,900	228,700
Totals . .	817,000	766,400
Number of furnaces:—		
Puddling furnaces	646	499
Hearths	51	34
Reheating furnaces	707	697

Of the 34 hearths at work in 1898, there were 26 low-hearths (*bas-foyers*) in Franche-Comté, Perigord, Landes, and Nièvre, 4 fineries in Nord and Allier, and 3 Catalan hearths in Pyrénées-Orientales. Six thousand tons of charcoal iron were made in these hearths in that year, but only 1700 tons of that amount were made from the charcoal pig produced in Perigord and Landes, the remainder being made from coke iron or from scrap. The hearth process and the direct treatment of ore have practically disappeared; they only supply an insignificant part of the total, and their products serve for very special purposes.

The 499 puddling furnaces working in 1898 were distributed through twenty departments, of which the leading ones are given below in the order of their out-turn:—

	Puddled Iron. Metric Tons.
Nord	225,930
Ardennes	62,773
Haute-Marne	53,889
Meurthe-et-Moselle	36,189
Saône-et-Loire	31,662
Loire	28,089
Allier	19,737
Jura	16,737
Oise	12,921
Ariège	12,304

The production in the department of Nord is thus accountable for 42 per cent. of the total.

The order of importance of the different districts as regards the yield of re-manufactured iron is practically the same as for puddled iron, with one exception. The department of the Seine takes the second place, although no puddling is carried on, with a production of 37,000 tons, mainly in the form of girders.

The increase in the output of re-manufactured material shows that it is more profitable to work up some kinds of old iron and scrap rather than to melt it down in the open-hearth furnace. This work is the mainstay of many small and scattered businesses which depend on a limited local demand for small sections.

The nature of the products in these two years is given in the table below:—

	1888.	1898.
	Metric Tons.	Metric Tons.
Merchant and special iron	699,100	695,700
Rails	800	200
Sheets and plates	117,100	70,500
Totals	817,000	766,400

Forty departments have contributed to these totals, but the combined output of eleven of them did not exceed a thousand tons. Steel tends to replace wrought iron altogether in the manufacture of sheets, and even of rails, which were only made of wrought iron in 1888, when they were of light section. The manufacture of merchant and special irons has, however, remained practically constant during the decade.

The average consumption of coal per ton of finished product has been reduced from 1·521 ton in 1888 to 1·305 ton in 1898. This saving of over 0·2 ton or 14 per cent. is due to improvements in the methods of heating and to a better utilisation of waste heat in the furnaces.

During last year, 1899, the production has again increased to 842,800 tons, or by 76,400 tons as compared with 1898.

As regards the external trade of the country, no great change is visible, as will be seen by inspection of the table below:—

	1888.	1898.	Increase.
	Metric Tons.	Metric Tons.	Metric Tons.
Imports	46,437	55,824	9,387
Exports	63,073	78,450	15,377
Surplus of exports . .	16,636	22,626	5,990

STEEL.

Comparison of Bessemer and Open-Hearth Steel Production.

The production of Bessemer and of open-hearth steel during this period has advanced by leaps and bounds, as the following figures will show:—

Ingots and Castings.	1888.	1898.	Increase.
	Metric Tons.	Metric Tons.	Per Cent.
Bessemer	403,300	883,600	119
Open-hearth	188,400	550,100	192
Totals	591,700	1,433,700	142

The next table shows the proportions of acid and basic steel produced. It will be seen that the greatest developments are in the basic Bessemer and the acid open-hearth processes.

	Bessemer.		Open-Hearth.	
	1888.	1898.	1888.	1898.
	Metric Tons.	Metric Tons.	Metric Tons.	Metric Tons.
Acid	219,800	245,600	154,000	355,000
Basic	183,500	638,000	34,400	195,100
Totals . .	403,300	883,600	188,400	550,100

The production of basic steel, which was only 37 per cent. in 1888, has increased to 58 per cent. of the total product in 1898.

The following table gives an account of the nature of the products made by the two processes in 1898:—

	Bessemer.	Open-Hearth.	Total.
	Metric Tons.	Metric Tons.	Metric Tons.
Rails	237,165	5,641	242,806
Sheets and plates	77,662	196,691	274,353
Merchant steel and special products, including cannon, forgings, axles, springs, and tires	347,550	260,431	607,981
Castings	9,300	10,000	19,300

Steel rails were rolled in eleven departments, but as a matter of fact 96 per cent. of the total was produced in six departments, where heavy sections for the great railway lines are made. In order of production these were:—Nord, 60,000 tons; Meurthe-et-Moselle, 54,000 tons; Pas-de-Calais, 46,000 tons; Gard, 51,000 tons; Landes, 25,000 tons; Loire-Inférieure, 18,000 tons.

Bessemer Steel.

Eleven departments have contributed to the total of the production of Bessemer steel, and the leading ones are as follows:—

	1888.	1898.
	Metric Tons.	Metric Tons.
Meurthe-et-Moselle	150,800	526,800
Nord	87,800	120,000
Pas-de-Calais	61,500	65,800
Saône-et-Loire	32,700	62,200
Landes	37,100	45,300
Gard	24,300	32,000
Loire-Inférieure	...	25,300
Loire	4,000	...
Totals	398,200	877,400
Other departments	5,100	6,200
Grand totals	403,300	883,600

The 5000 tons in 1888 and the 6200 tons in 1898 were steel castings made with the aid of special small converters, of which there were four in 1888 and eight in 1898. Apart from these small vessels, the steel was made in twenty-four converters in the former and in thirty-two converters in the latter year. The average annual out-turn per converter has thus increased from 17,000 to 26,000 tons.

The major portion of the increase, more than 78 per cent., is due to Meurthe-et-Moselle. In this department there are Bessemer converters at Mont-Saint-Martin, belonging to the Société anonyme des Acieries de Longwy, at Joeuf belonging to Messrs. Wendel & Co., at Micheville belonging to the Société anonyme des Acieries de Micheville, and at Pompey belonging to Messrs. Fould-Dupont & Co. The two latter steelworks have been built since 1888. Another steelworks with three 8-ton converters, built by the Société des Forges de Montataire, has commenced operations this year.

The production of this department of Meurthe-et-Moselle is nearly 60 per cent. of the total of the country, but it will soon become much greater on account of the erection of two new steelworks which have already been commenced. One of these at Neuves-Maisons, with three 15-ton converters, belongs to the Compagnie des Forges de Chatillon, Commentry et Neuves-Maisons, while the other, also with three 15-ton vessels, is being built at Homécourt by the Société anonyme de Vezin-Aulnoye.

The rolled products made from Bessemer steel in 1898 in this department included 54,297 tons of rails, 143,500 tons of merchant and other special steel, and 19,289 tons of plates. In addition 217,000 tons of ingots, blooms, and billets were sent as far as the Loire and Bouches-du-Rhône for further treatment.

Basic Bessemer steel is also made in the department of Nord and at Le Creusot. Of the 120,000 tons of steel made in Nord in 1898, 49,000 tons were produced in basic-lined converters by the Société anonyme des Hauts-Fourneaux, Forges et Acieries de Denain et d'Anzin, at Denain, and by the Société anonyme des Forges et Aciéries du Nord et de l'Est at Trith-Saint-Leger.

The other Bessemer steelworks are as follows:—The works of the Société anonyme des Aciéries de France at Isbergues in Pas-de-Calais; Messrs. Schneider & Co.'s works at Le Creusot; the works of the Société des Hauts-Fourneaux, Forges et Aciéries de la Marine et des Chemins de Fer at Boucau in the Landes; the works of the Compagnie des Mines, Fonderies et Forges d'Alais at Bessèges in Gard; and the works of the Sociéte anonyme des Aciéries, Hauts-Fourneaux et Forges de Trignac at Trignac in Loire-Inférieure.

The production of ingots and castings of Bessemer steel in 1899 was 930,800 tons, that is, 47,200 tons, or 5 per cent. more than in the preceding year.

Open-Hearth Steel.

During 1898 open-hearth steel was made in twenty-one departments, to the extent shown by the following table, which gives the figures for 1888 for the sake of comparison:—

	1888.	1898.
	Metric Tons.	Metric Tons.
Nord	12,800	98,000
Saône-et-Loire	35,380	80,709
Loire	45,700	60,881
Loire-Inférieure	8,667	46,603
Allier	11,800	38,182
Gard	20,029	33,704
Nièvre	9,000	25,824
Morbihan	12,500	25,106
Oise	2,258	22,307
Meurthe-et-Moselle	1,635	18,525
Haute-Marne	3,405	17,376
Aveyron	...	17,039
Pas-de-Calais	...	12,720
Landes	2,132	10,626
Ardennes	3,930	8,680
Isère	2,836	6,986
Meuse	4,950	6,522
Jura	6,870	5,843
Ariège	1,421	5,231
Haute-Rhin	3,144	4,910
Doubs	...	4,347
Totals	188,457	550,121

This production was obtained from fifty-nine furnaces in 1888, and from eighty-five in 1898, so the average annual out-turn per furnace has increased from 3225 to 6472 tons, or 100 per cent. There are now thirty-five works containing open-hearth furnaces, as against eleven with Bessemer converters, neglecting the small converters for special castings, but no particular department has a preponderating position in the manufacture, as is the case with the Bessemer process. The department of Nord takes the lead, but even there only 18 per cent. of the total is made.

The increase in the production of open-hearth steel during this period has amounted to 361,700 tons, or 192 per cent. of the production in 1888. Three-quarters of this increase, namely, 271,000 tons, is acid steel, and the remaining quarter, 90,000 tons, is basic steel. The chief centres for the manufacture of the latter are—Nord, 32,000 tons, and Saône-et-Loire, 30,000 tons; Morbihan, Nièvre, 25,000 tons; and the departments of Meurthe-et-Moselle, Aveyron, Haute-Marne, Ardennes, Meuse, Jura, and Haute-Rhin.

The production of ingots and steel castings from open-hearth furnaces in 1899 was 59,400 tons, an increase of 48,300 tons or 8 per cent. over the previous year.

Miscellaneous Steel.

In addition to Bessemer and open-hearth steel, a certain quantity of puddled, cement, and crucible steel is also made, to the extent shown in the next table:—

	1888.	1898.
	Metric Tons.	Metric Tons.
Puddled and natural steel	13,118	6,632
Blister steel	1,342	1,215
Crucible cast steel	9,400	16,458
Totals	23,860	20,305

In 1899 the production amounted to 26,123 tons.

The chief centres for the manufacture of these kinds of steels were as follows in 1898:—

a. Puddled and natural steel were made in seventeen departments, including Loire, 2000 tons, Isère, 1200 tons, Meurthe-et-Moselle, 1600 tons, and Tarn, 1400 tons. In Allier only 60 tons were made, as compared with 3600 tons in 1888, and similarly the production of Ariège has fallen from 1360 to 292 tons, and of Nièvre from 1300 to 20 tons. In 1898 there were still twenty-four steel-puddling furnaces, besides one steel hearth in Loire.

b. Blister steel was made in nine departments, of which Loire produced 500 tons; Tarn, 200 tons, and Isère, 180 tons, and there were thirty-nine furnaces.

c. *Crucible cast steel* was made in the departments of Loire, 11,800 tons; Tarn, 1600 tons; Allier, 1200 tons; Ardennes, 845 tons; Isère, 608 tons; Nord, 250 tons, and elsewhere. Altogether ten departments contributed, the number of furnaces being fifty-three, with 664 crucibles.

To the production of various kinds of steel mentioned above may be added the out-turn of re-manufactured old steel, which was 9900 tons in 1888, 5300 tons in 1898, and 9000 tons in 1899. This gives the following totals for the steel made in France in three years:—

	1888.	1898.	1899.
	Metric Tons.	Metric Tons.	Metric Tons.
Production	625,460	1,459,300	1,564,300

External trade in steel has not suffered any great change, as will be seen from the following table:—

	1888.	1898.	Increase.
	Metric Tons.	Metric Tons.	Metric Tons.
Imports	10,000	10,300	300
Exports	35,200	72,200	37,000

RECENT PROGRESS.

Not only has there been great progress in the iron and steel industry, as shown by the preceding statistics, but many and important changes have been made in plant and machinery, and in the composition and quality of the products.

In Bessemer steelworks, the principal innovation, especially in the eastern districts, consists in the employment of metal mixers, which not only ensure a more regular composition in the iron used, but also desulphurise it and render the steelworks independent of blast-furnace variations. The basic converter has also been subjected to several improvements in details, to effect a greater regularity in the working and in the composition of the out-turn.

The open-hearth method has also been improved in several respects, both as regards the furnace itself and the system of charging. Gas-producers and regenerators, too, have been modified, and much economy has resulted as compared with the older forms. The tendency to increase the size of the furnace is strongly marked, and at the present time a number of works own furnaces capable of holding 40 tons or more.

On account of the great and increasing use of steel castings, a certain number of open-hearth furnaces are devoted exclusively to their manufacture, instead of making occasional casts, and this branch has become of the greatest importance in a number of large works. Some works also employ converters which are used to supply metal for large castings, and other works confine themselves to the manufacture of steel castings with small converters.

Included in the category of novel practice are the powerful plants which have been erected within the last few years for compressing liquid steel in order to obtain metal free from blowholes. At Le Creusot, the pressure is applied to the upper part of the ingot, and at St. Etienne the ingot is pressed towards the narrow end of a conical ingot mould. The question of the suppression of blowholes has also made great advances, due to the use of certain additions—especially aluminium. Note should also be taken of the successful recarburisation of steel made in the basic furnace to produce hard steel from the milder qualities.

The increase in the production of ingots has been followed by an increase in the power of rolling-mills, especially of plate-mills. In 1898, 530 trains were at work as compared with 502 in 1888 for rolling iron and steel.

The horse-power has not altered to any extent as far as hydraulic machinery is concerned, 413 machines of 12,681 horse-power in 1898 being used in place of 491 of 12,940 horse-power in 1888, but the number, and, to a still greater extent, the horse-power of the steam-engines in the various ironworks, have wonderfully developed. In 1898 there were 2285 engines with a horse-power of 169,200 in place of 1976 engines rated at

96,586 horse-power in 1888. The power has thus increased by 72,614 or 75 per cent.

Concurrently with the introduction of improvements into the plant, the composition has formed the subject of much investigation. With the view of increasing the elastic limit, the tensile strength, the elongation, the hardness and other properties of steel, much attention has been directed to the study of new alloys with chromium, nickel, manganese, tungsten, silicon, &c. The percentage of these foreign elements has been increased in these special steels, which are not only made in the crucible, but are manufactured in large quantities in the open-hearth furnace. Especially is this the case with nickel and chrome steel, which possess such valuable properties, and they are regularly made in a basic-lined furnace. A knowledge of the proper treatment for overcoming the serious difficulties presented in the working of these rich alloys has been gained, though their properties are so often modified by unexpected conditions in operations of forging, hardening, and annealing. In order to roll these special steels, a notable increase has had to be made in the power and speed of the mills, because the temperature limits for their treatment are much more restricted than is the case with ordinary carbon steels.

Upon the whole, during the period under consideration, 1888 to 1898, the production of cast iron has increased 884,000 tons, of wrought iron 25,800 tons, and of steel 937,400 tons. This far surpasses the development of the iron industry during the period 1877 to 1888, which corresponds with the interval between the two previous Exhibitions held at Paris. Then steel only increased 322,626 tons and cast iron 176,522, while there was a decrease in wrought iron of 67,520 tons.

Certainly as far as technical progress is concerned, there is nothing in 1900 at all comparable with the advances made in the intervals between the preceding Exhibitions in the Bessemer process, in the manufacture of open-hearth steel, and in the basic method of dephosphorisation. Nevertheless great progress has been made on the one hand in increasing the power of the appliances used, and on the other hand in the quality and composition of the products.

The tendency to replace cast iron by cast steel grows, since progress in the steel-foundry facilitates the production of more delicate and more important work. In France, success has attended endeavours to cast complicated forms in metal which is both tough and of high tensile strength.

For rolled and forged products there are special steels available, and their mechanical properties vary within much wider limits than carbon steel, while they are much more suitable for the special requirements of particular applications such as the growing exigencies of armour plate.

DISCUSSION.

The **President** said he need not express the gratitude of the members for such an acceptable paper.

Mr. **Greiner**, Member of Council, said: I owe probably to my position as a foreign member of the Institute Council, the honour of saying a few words on the subject of the paper which has just been read to you, for really I do not know that I have any other authority. It is, nevertheless, sufficient to allow me to say that we must proclaim the work of Mr. Pinget to be of the greatest interest and merit. He gives us a very complete history of what has been done in France during recent years, and if, as the author very truly says, no great inventions have been forthcoming in the metallurgical world, it is none the less true that France has been found to be a very fertile country in applying the inventions of recent years; and with regard to what concerns me more particularly, I can say that there is probably no other country which has better understood the application of the scientific ideas of recent years than France; there is probably not a country where they make steel and iron, but especially steel, so carefully and so scientifically, and produce such varied and such excellent work as in France. I give this testimony before Englishmen. I am quite certain that no one will contradict me. The number of Frenchmen who have devoted their lives to forming and producing steels of a delicacy and of an excellence which is to-day known throughout the world is a very large one. From this point of view Mr. Pinget's paper deserves to be read. I think that the whole meeting would like to join with me, and that I shall be the interpreter of the Iron and Steel Institute in thanking its author for having presented it to us in such a clear and striking manner as he has done.

Sir **Lowthian Bell**, Bart., Past-President, said the review of the progress of the science which it had been their duty to cultivate for a great many years was of very great importance. He had read the paper, and he could speak with some little authority upon it, and he ventured to say that there was no paper on that subject which excelled the one they had just heard read.

Mr. WILLIAM WHITWELL, President-elect, said they were exceedingly indebted to the author of the paper for the details, which were so clear, succinct, and admirable, that the most ignorant of them might gain something from its perusal.

Mr. J. E. STEAD, Member of Council, then gave a summary of the following paper, which was illustrated by wall diagrams.

IRON AND PHOSPHORUS.

BY J. E. STEAD, F.I.C.

PART I.

ACCORDING to (2) Dr. Percy,* no less than seven definite chemical compounds of phosphorus and iron, or at least compounds containing definite atomic proportions of these elements, have been isolated. They are as follows:—

	Fe_6P.	Fe_3P.	Fe_2P.	Fe_4P_3.	Fe_5P_4.	FeP.	Fe_3P_4.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Iron . .	91·54	84·42	78·32	70·67	69·31	64·37	57·54
Phosphorus	8·46	15·58	21·68	29·33	30·69	35·63	42·46

Since Percy's time no very elaborate research has been made, but various workers have added to our knowledge from time to time. What has been done in recent years, however, has enabled metallurgists to see that they had yet much to learn, and that the last word has not been written about the relation which exists between iron and phosphorus.

Excepting in a short note by (8) Professor Arnold, there has been little published respecting the microstructure of iron and steel containing phosphorus; and as this branch of the research has practically remained untouched, I have, with the co-operation of a large number of metallurgical friends and assistants, during the last few years devoted much time in endeavouring to clear away the fog which surrounds the subject by studying with the aid of the microscope and chemical analysis. The results have far exceeded anticipation, but there still remains much to be done; and it is sincerely wished that metallurgical students will not only repeat the original experimental work recorded, but will follow up the research from the point where it has been left.

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* The small figures coincide with the index numbers of the Bibliography in Appendix V.

Preparation of Specimens.

In the prosecution of the research it was necessary to prepare many hundreds of specimens containing from traces up to a very large amount of phosphorus. The class of steels, or rather irons, containing under 1 per cent. of phosphorus were prepared for me by Mr. C. H. Ridsdale through the kind permission of Mr. Arthur Cooper, and by Mr. Arthur Richards of the Cleveland Steelworks. They consisted of samples taken from the Bessemer converter during the after-blow, when practically all elements other than phosphorus and iron had been removed. For the samples containing from 1 per cent. to 2 per cent. phosphorus I am indebted to Messrs. J. H. Andrew & Co., Ltd., of Sheffield, who made several crucible melts of the purest Swedish bar iron and phosphorus, which latter was simply dropped into the crucibles containing the pieces of bar in a white hot state.

The metals with higher percentages of phosphorus were prepared in my own laboratory by melting either Swedish iron or ordinary puddled iron in crucibles with phosphorus.

Other samples of a curious and interesting nature were produced incidentally in iron manufacturing processes.

Classification of Results.

The results of the examination of iron and phosphorus may be conveniently divided into the following classes:—

1st Class. In this class are included all compounds containing between 0 per cent. and about 1·70 per cent. phosphorus.

2nd Class. Compounds containing between about 1·70 per cent. and about 10·2 per cent. phosphorus.

3rd Class. Compounds containing between about 10·2 per cent. and 15·58 per cent. phosphorus.

4th Class. Compounds with from 15·58 per cent. to 21·68 per cent. phosphorus.

The metals containing much above 21 per cent. phosphorus have not been investigated, as they are of little metallurgical interest.

CLASS I.

Phosphorus from traces to about 1·70 per cent.

The preliminary examination of a few samples containing between 1 per cent. and 2 per cent. phosphorus clearly showed in the latter two distinct constituents, one consisting of crystalline grains, the other of a hard constituent enveloping the grains, closely resembling carbide of iron or cementite.

The samples containing between 1 per cent. and 1·4 per cent. were quite free from the hard constituent. It thus became clear that in iron containing between 1·4 per cent. and 2 per cent. phosphorus there must exist a critical point.

After making many "melts" and careful micro-examinations of the specimens prepared, one of the small masses of metal, which had been allowed to cool *very slowly* in the crucible, on sectioning and inspection, was found to be free from the hard constituent near the outside, but contained much of it in the central portions. The exterior part was cut off and carefully analysed, with the following result:—

	Per Cent.
Carbon	0·02
Silicon	trace
Sulphur	0·03
Phosphorus	1·63
Manganese	trace

Valuable data was also obtained from a very crystalline piece of metal which was found lodged between the bricks in a puddling furnace, and was taken out when the furnace was off for repairs.

The crystalline particles were arranged in columnar form, which averaged about one inch in length. The macrostructure had much the same appearance, on a small scale, of the basaltic formation at Staffa. Fracture was readily effected along the columnar junctions. Each complete column constituted a single allotriomorphic crystal, and its external form had no relation to the orientation or cleavages, which were different in each parallel column. They were quite free from carbon, silicon, and manganese.

On examination of sections made vertically and horizontally through the columnar masses, the columns were found to be enveloped by the hard constituent above referred to.

The following is an analysis of this interesting specimen:—

	Per Cent.
Iron	97·30
Carbon	Nil.
Silicon	Nil.
Manganese	Nil.
Sulphur	0·33
Phosphorus	1·86
	99·49

By crushing and sieving off the finer powder, most of the hard constituent and free sulphide of iron was got rid of, and by treating the metallic powder with dilute acid, practically all the sulphides were dissolved away. The residue was washed with water, alcohol, and ether, dried and tested. It still contained some of the hard constituent. By analysis it was found to contain—

	Per Cent.
Iron	98·00
Carbon	Nil.
Manganese	Nil.
Silicon	Nil.
Sulphur	0·07
Phosphorus	1·77
	99·84

By a method presently to be described, the hard constituent was separated and independently examined. It had almost exactly the composition demanded by the chemical formula Fe_8P. The actual amount of free phosphide present was equal to 0·103 per cent. phosphorus, or 0·766 per cent. Fe_8P.

The constitutional analysis of this specimen is as follows:—

			Per Cent.
Crystalline columns	Iron	97·217	98·884
	Phosphorus	1·667	
Free constituent	Phosphide of iron (free)		0·766
	Sulphide of iron		0·190
			99·840

A further trial was made on material practically free from carbon, silicon, sulphur, and manganese, but which contained more than 1·7 per cent. phosphorus. Instead of cooling the melted mass by allowing the crucible to remain in the fire, as soon as the metal was perfectly fused the crucible with contents was removed, and the solidification allowed to proceed rapidly.

The object of this more rapid cooling was to ascertain whether or not more phosphide, under such conditions, would be left in the crystalline mass. The analysis of the metal was as follows:—

	Per Cent.
Iron	97·35
Carbon	0·02
Manganese	Nil.
Silicon	Nil.
Phosphorus	1·94
Oxygen, &c.	0·69
	100·00
Phosphorus in free phosphide	0·19
Phosphorus in the crystalline mass	1·75

It is apparent, then, that iron will retain, at its solidifying point, between 1·63 per cent. and 1·75 per cent. phosphorus, the amount varying slightly according as the passage from the liquid to the solid state is rapid or retarded.

Under normal conditions of cooling, in which the molten metal is withdrawn from the fire and allowed to solidify in the crucible, it may be accepted that 1·70 per cent. phosphorus will be retained in the crystalline mass, and that any of the element exceeding 1·70 per cent. will fall out of solution in the definite compound Fe_3P, which will then form cell walls to the crystalline grains or irregular-shaped eutectic* masses distributed throughout the metal.

Judging from the variable amount of phosphide retained by the iron at its solidifying point, and the ease with which some of what is so retained can be thrown out of solid solution,† proof of which will be given later, I am justified in concluding that all the crystalline compounds containing no free phosphide of iron (triferric phosphide) are solid solutions in iron, not of phosphorus, but of the definite chemical compound Fe_3P.

On the Action of Reagents on the Metals of Class I.

Metals containing between 0·10 per cent. and 1·70 per cent. phosphorus leave a black residue on treatment with dilute hydrochloric acid or sulphuric acid. The amount of the insoluble residue increases with the phosphorus. The less the phosphorus the slower is the action of the acid.

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* Notes on eutectics will be found in Appendix I.

† Notes on solid solutions will be found in Appendix II.

Metal with 1 per cent. of phosphorus dissolves more than twice as rapidly as one with 0·05 per cent.

The black residue is completely oxidised by a ferric salt, and by that means is distinguished from a carbon residue. When washed rapidly and dried at 60° over sulphuric acid, and afterwards heated to 80° or 90° C., it spontaneously ignites and burns with a phosphoretic flame. If it is washed with alcohol and ether this peculiarity does not appear.

After dissolving in dilute hydrochloric acid an iron containing about 1 per cent. phosphorus, on long-continued boiling of the solution some of the black decomposition product of Fe_3P suspended in it is dissolved, yielding a dark brown solution, the colour of which is destroyed by ferric chloride.

(14) Messrs. Osmond and Werth have made a preliminary examination of the black residue, and they state that it contains phosphorus, iron, oxygen, hydrogen, and water.

It is of very complicated composition, and, beyond confirming the observations of the gentlemen just named and determining the ratio of the iron to the phosphorus present, I have not more thoroughly examined it.

Two samples containing about 1·7 per cent. phosphorus were dissolved in cold dilute hydrochloric acid. The residues were filtered off, washed with water, and dissolved off the filter in acidulated bromine water. The solutions were examined for iron and phosphorus. The results showed an atomic relation, viz.:—

In 1st sample	$FeP_{1·66}$
In 2nd sample	$FeP_{1·85}$

It was observed that the ratio of iron to phosphorus was materially influenced by boiling the solution of the dissolved iron and the length of time the boiling was continued.

The black residues were not attracted by the magnet.

When pure triferric phosphide, Fe_3P, was digested in cold dilute hydrochloric acid in an open vessel for several days, the metallic lustre was removed and the powder changed to a dense black substance. During this treatment streams of gas were evolved. The residue was not attracted by the magnet. It was filtered, washed, and tested for iron and phosphorus. In two separate specimens of Fe_3P, one was kept in contact with the acid for two weeks, the other for four days. The atomic ratio of the iron and phosphorus in the black residue was as follows:—

1st sample, treated with acid for 14 days = $FeP_{1\cdot75}$
2nd sample, treated with acid for 4 days = $FeP_{1\cdot80}$

The fact that the long-continued action of hydrochloric acid on Fe_3P leaves a black non-magnetic residue similar, as regards the ratio of the iron to phosphorus, to the residues from iron and phosphorus compounds containing no free phosphide, is strong evidence in proof that such compounds are solidified solutions of phosphide of iron in iron.

There can be no doubt that the residues in both cases are decomposition products, and are not definite chemical compounds.

The property of spontaneous combustion at 80° C. may possibly be due to the presence of one of the higher hydrides of phosphorus.

The study of these residues is a research in itself, and one which must be carefully followed before we can feel justified in forming definite conclusions.

On etching together in dilute acids polished pieces of iron or steel containing varying proportions of phosphorus, they darken relatively with the proportion of phosphorus present. Taking advantage of this observation, I have found it valuable in detecting the segregation of phosphorus in soft steel bars; for where there was most phosphorus the ferrite darkened relatively more rapidly (on the continued acid of dilute acid) than did the ferrite in the portion external to the segregate.

An instance of this has quite recently come under my notice. A test-piece cut from a gun-forging, on etching, darkened relatively more rapidly in one part than in the greater mass of the section. On drilling out the dark and light portions and subjecting them to chemical analysis, the phosphorus was found to be 0·12 per cent. in the dark portion, whilst the light part contained only 0·03 per cent. As the bar failed to stand the regulation test entirely owing to the segregation, it is reasonable to conclude that if a steel shaft, or other structure which has been turned up at one end in a lathe and roughly polished on ordinary fine emery paper, were to be placed in, or washed by, dilute acid for a minute or two, such segregation would be at once detected. I have actually tested many samples in this way, and have proved beyond doubt that it is a safe and reliable method. The advantage is that it can be applied to the steel in the machine-shop, and does not require the assistance of an experienced metallographist.

It should be remarked in passing that it frequently and nearly always happens that where the phosphorus is segregated, both carbon and sulphur are also concentrated, so that in carbon steels the darkening produced is caused by an increased proportion of pearlite and sulphide of manganese in addition to the phosphorus. The test, however, is the more valuable on that account.

(14) Osmond and Werth have shown that on treating steels, &c., containing phosphorus, with dilute hydrochloric acid, a portion of the phosphorus passes off as PH_3, and that generally the freer from carbon the greater is the proportion so evolved. The actual proportion of the whole amount given off as PH_3 on dissolving blown Bessemer steel, before the spiegel was added to it, amounted to about two-thirds.

In a soft steel containing only 0·18 per cent. carbon, 71 per cent. of the phosphorus was gasified.

In the case of a sample of burnt Moselle iron, however, which contained 0·81 per cent. phosphorus and 0·11 per cent. carbon, only 18 per cent. was evolved as PH_3.

Messrs. Osmond and Werth remark that the quantity evolved depends also upon the strength of the acid.

(11) Baron Jüptner's results, obtained by dissolving the metals in dilute sulphuric acid and absorbing the PH_3 in neutral nitrate of silver solution, are somewhat different from those quoted. In the case of certain steels with under 0·1 per cent. phosphorus and about 0·16 per cent. carbon, only about 30 per cent. of the total passed off as PH_3 instead of 71 per cent. When the phosphorus was 0·6 per cent. with carbon 0·12 per cent., only 3 per cent. was evolved as gas.

Both researches, however, show that with high phosphorus there is very little of it converted into PH_3.

In order to ascertain if my own experiment would confirm these results, I examined a set of specimens containing between 0·07 and 1·70 per cent. phosphorus, obtained for me by Mr. Arthur Richards, director of steelmaking at the Cleveland

Works. They were taken from a charge of metal in a basic-lined converter during the after-blow. The small ingots were much honeycombed, but, for all that, a sufficient quantity of clean drillings was obtained from each upon which to experiment. In each case one gramme of drillings was used. They were dissolved under different conditions. One set was dissolved in strong concentrated hydrochloric acid, using 20 c.c. of acid. Solution was accelerated by heating. When dissolved, the solutions were just brought to the boiling-point. They were then oxidised with nitric acid, well boiled, and finally the phosphorus remaining in the solution was gravimetrically determined.

In a second series the same treatment was followed, with the exception that the acid was diluted with an equal volume of water.

In a third series the treatment was the same as in the second, excepting that solution was allowed to take place in the cold.

The total phosphorus having been determined in each case, the difference between that obtained by the special treatment and the total was accepted as that portion which had passed off as gas. This method was much easier to work than that of Osmond and Jüptner, and had the advantage that a large number of assays could be made simultaneously.

The results obtained were as follows:—

Analyses of Samples.

	1.	2.	3.	4.	5.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Iron	97·80	98·20	98·70	98·90	99·60
Carbon	0·06	0·05	0·05	0·04	0·04
Phosphorus	1·69	1·32	0·62	0·23	0·065
Not determined	0·45	0·43	0·63	0·83	0·295
	100·00	100·00	100·00	100·00	100·00
Dissolved in strong hot acid, 1 grm. iron to 20 c.c. HCl.					
Phosphorus evolved as PH_3	0·26	0·42	0·30	0·17	0·052
Phosphorus in residue .	1·33	0·91	0·32	0·06	0·016
Per cent. gasified . .	15·00	33·00	48·00	74·00	80·000
Dissolved in weak hot acid.					
Phosphorus evolved as PH_3	0·28	0·26	0·14	0·11	0·028
Phosphorus in residue .	1·41	1·06	0·48	0·12	0·037
Per cent. gasified . .	16·00	20·00	23·5	48·00	74·000
Dissolved in weak cold acid.					
Phosphorus evolved as PH_3	0·06	0·09	0·07	0·11	0·035
Phosphorus in residue .	1·63	1·23	0·55	0·12	0·030
Per cent. gasified . .	3·5	6·5	11·00	48·00	54·000

These results, although varying with the way the metal is dissolved, show clearly enough that the more dilute the solid solution of the phosphorus in iron, the greater the proportion of phosphine, PH_3, gas which is formed.

They also show that, if any comparison has to be made, the chemical treatment must be identical. The strength of acid, the temperature, and the time the solutions are boiled after the irons are dissolved, all have an influence on the proportion of phosphine gas formed.

The following results were obtained by dissolving one gramme of each sample in 10 c.c. strong hydrochloric acid in the cold, and boiling afterwards for one minute.

The samples were obtained from different charges during the after-blow period.

Nos.	Phosphorus.			
	Gasified.	Not Gasified.	Total.	Parts per 100 Gasified.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	0·260	0·63	0·89	30·00
2	0·18	0·34	0·52	34·00
3	0·12	0·18	0·30	40·00
4	0·09	0·09	0·18	50·00
5	0·03	0·03	0·06	60·00

Many other cases might be brought forward, but they go to prove that the higher the concentration of the solid solution, the less proportion of the total phosphorus which is given off as PH_3—a most important general law, as will be seen in Part II. of this paper.

Cupric chloride, although it has little action on free Fe_3P, behaves like sulphuric and hydrochloric acid in one respect, that when acting on solid phosphide solutions it leaves a black decomposition product.

(14) Osmond and Werth have found that the residue left on dissolving these metals electrically by Weyl's method resembles that left by dilute acids.

There is much room for hypothetical and inductive reasoning to account for the facts, and it is hoped that members of this Institute will endeavour to find a satisfactory solution to account for the phenomena. A probable explanation is that the more attenuated the phosphide, and the greater the proportion of iron, and the more nascent hydrogen available, the more readily the phosphide will be decomposed and hydrogenised.

Certain results of Baron Jüptner, referred to subsequently, do not appear to confirm such a view; it is therefore necessary to await the results of further research before we can form other than tentative conclusions, seems to point in the direction that the more diffused the phosphorus, and the greater the proportion of phosphine formed, the safer the steel.

This question, however, will be further discussed in Part II., when the influence of carbon is considered.

When nitric acid of specific gravity 1·42 is poured upon iron containing little phosphorus, the iron becomes passive, and will not dissolve until the solution is heated; but when the percentage of phosphorus is high, say between 0·6 per cent. and 1·7 per cent., the passivity disappears and the acid attacks the metal violently.

In very dilute solutions its action resembles that of sulphuric and hydrochloric acids, ferrous nitrate and the black decomposition product being formed.

With nitric acid of specific gravity 1·20, and at a temperature of about 20° C., a perfectly clear solution results, free from any black decomposition product, whilst under like conditions free phosphide of iron, Fe_3P, is but little acted upon. This reagent then is a very good one for separating free phosphide from phosphide of iron in solid solution. Practically all the results showing the amount of free phosphide of iron given in this paper were obtained by a method based upon this behaviour of nitric acid. Details of the method are given in Appendix III.

The Effect of Annealing Iron saturated with Phosphide of Iron.

The next question which arose was, will phosphide of iron separate from the solid saturated compound containing above 1·8 per cent. of phosphorus by annealing and slow cooling?

To answer this, a large piece of metal, containing about 1·8 per cent. phosphorus and 0·18 per cent. carbon, was passed repeatedly through a furnace used for the manufacture of malleable castings.

The sample was placed in the centre of the furnace near the top. It was packed in an iron box with a mixture of five parts of old ore and one part of new.

After closing the oven, the fire was started and it was fired continuously for thirty-six hours to get up the full heat. This was maintained for ninety-six hours. It was cooled down in about forty hours, and was then removed. The temperature was estimated to be 900° C.

The same treatment was repeated a second time.

The object of using this furnace was twofold: first, to remove the carbon; second, to maintain the metal at a temperature of near 900° C. for a long period, and to cool down from that temperature very slowly.

The metal, although 20 cm. in thickness, was completely decarburised. Drillings were taken from different parts of it and separately analysed, with the following results, viz.:—

	Before Treatment.	Outside ¼ In.	½ In. below Top.	¼ In. from Bottom.	½ In. from Bottom.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Iron	97·20	96·96	97·60	97·40	97·80
Carbon	0·18	...	trace	trace	trace
Manganese	trace	trace	trace	trace	trace
Silicon	trace	trace	trace	trace	trace
Sulphur	0·02	0·02	0·02	0·02	0·02
Phosphorus	1·82	1·63	1·85	1·94	1·78
Oxygen, &c.	0·78	1·39	0·53	0·64	0·40
	100·00	100·00	100·00	100·00	100·00
Phosphorus in free Fe_3P	0·51	0·28	0·92	0·88	0·80
Phosphorus in solid solution	1·31	1·35	0·93	1·06	0·98
Total*	1·82	1·63	1·85	1·94	1·78
Phosphorus thrown out of solid solution	...	?	0·41	0·37	0·29

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* It will be noticed that the amount of phosphorus is very variable in the same piece, a peculiarity of all rather large pieces of iron containing much phosphorus. The ingot from which this was obtained weighed only about 14 kilos., yet the phosphorus varied between 1·6 per cent. and 2·4 per cent. in drillings taken from different parts. As a rule, in slowly cooled ingots my experience is that the highest phosphorus was generally found near the top.

The outside layer was very spongy and porous, and contained oxide of iron in considerable quantity.

In this layer it was noticed, on micro-examination, that the areas which had been originally filled with phosphide eutectic were quite empty. It had evidently run out, and had been absorbed in the spongy oxide surrounding it, leaving cavities of the characteristic shape shown in Photo No. 8. In no other parts excepting these could the cavities be detected.

It is probable that the figure 1·35 per cent. does not correctly represent the phosphide held in the iron, as some of it was no doubt in the state of phosphoric acid. The other analyses made on the solid and non-oxidised material indicate beyond doubt that, on long annealing the metal saturated with phosphide at its solidifying point, a portion of that substance separates out, leaving the mass with only about 1 per cent. phosphorus.

This most interesting experiment disposes of the conception that the solid solution at the solidifying point, containing about 1·70 per cent. phosphorus, is a definite chemical compound.

In order to ascertain whether a portion of what separated on annealing at about 900° C. would recombine at 1100° and 1300°, and after melting, portions of the annealed metals were heated for half-an-hour at these temperatures, and a third portion was melted in a magnesia crucible. They were then cooled and analysed. The following were the results obtained:—

	Heated to 1100° C.	Heated to 1300° C.	Melted.
	Per Cent.	Per Cent.	Per Cent.
Phosphorus in free phosphide . .	0·95	0·91	0·20
Phosphorus in solid solution . .	1·01	1·06	1·74
	1·96	1·97	1·94

They show clearly enough that even at 1300° C., a point not far removed from the point of fusion, practically no phosphide was reabsorbed.

Microscopic Examination of the Annealed Metal.

A section of the metal before annealing and decarburising is represented in Photo No. 8, in which it will be seen the phosphide eutectic is present in irregular masses and is surrounded by dark fringes of pearlite. After decarburisation the pearlite was absent, and what is most remarkable, the phosphide of the phosphide eutectic was found not in irregular masses, but in what appeared to be rectilinear prisms, many terminals of which had true crystalline angles.

They were not always continuous, but were generally much broken up. Photo No. 20 illustrates this.

In the specimen heated for half-an-hour to 1100° C. the change was also remarkable. Most of the prismatic crystals retained their position, but the ends were quite rounded. Many of them had broken up and contracted, forming chains of globules or lenticular-shaped bodies, the longer axes of which invariably corresponded to the longer axes of the original prisms. There were also present irregular-shaped masses of eutectic somewhat resembling those of the sample before it was annealed.

In the specimen heated to 1300° C., the prismatic formation and the globular particles of phosphide were entirely absent, and had been replaced by the irregular-shaped eutectic masses.

Photo No. 21 illustrates this.

On remelting a portion of the annealed material, the micro-structure was similar to No. 8 if the pearlite is excluded.

In looking at the three photos, Nos. 8, 20, 21, placed side by side, one is impressed with the facts: 1st, That by annealing, the phosphide illustrated in Photo No. 8 has entirely rearranged its position, and must either have diffused and crystallised in the new order, or grown out of the old position, the liquid eutectic being the reservoir or base, supplemented by what fell out of solution during the long-continued heating. 2nd, That on heating to above the melting-point of the eutectic and phosphide of iron, the latter, becoming liquid, separated into oblong and globular drops, and combined with a portion of the surrounding metal, formed a fusible eutectic the separate portions of which coalesced to form the irregular masses shown in Photo No. 8. I cannot offer any explanation as to why it should take this particular form. 3rd, That the molecular movement of the ground mass must have been very great, behaving almost as if it was a viscous fluid, in rearranging its position to suit the altered areas occupied by the eutectic.

Physical Properties.

The peculiar property of brittleness which phosphorus gives iron is well known, and it is the universal opinion that that element is the most objectionable of all the metalloids which enter into the composition of steel and iron.

Various observers do not agree exactly as to the effect of phosphorus on the physical properties. (19) Professor Howe, in his work on "The Metallurgy of Steel," gives a condensed account of the results obtained by many observers, and forms the following conclusions:—

"1st. We may infer that when the phosphorus is above, say, 0·12 per cent., it probably has no important constant effect, for if it had, the analysis of statistics should yield concordant results.

"2nd. Phosphorus usually raises the elastic limit, and thus the elastic ratio, an index of brittleness; indeed, the elastic limit and breaking strength of steel occasionally coincide."

The whole question as to the effect of phosphorus requires to be reinvestigated, and such investigations must not be confined to chemical analyses and mechanical behaviour in the testing-machine, but should include the character of the microstructure, and more particularly the orientation and size of the crystalline grains.

The great variations in the mechanical properties of phosphoretic steels containing approximately the same amount of phosphorus most probably is caused by difference in structure. I have myself obtained widely different results from the same high phosphorus steel by treating it so as to obtain such variations.

(8) Professor Arnold has given the results on examining iron containing 1·37 per cent. phosphorus and 0·07 per cent. carbon.

Such iron may be considered as nearly saturated with phosphide of iron, and to have the following constitutional analysis:—

	Per Cent.
Iron	90·16
Phosphide of iron in solid solution	8·79
Carbide of iron	1·05
	100·00

It was drilled and turned with difficulty. On etching, the crystalline joints appeared to be readily penetrated by the etching acid. The mechanical tests, compared with carbon steel and nearly pure iron, were as follows :—

Test Pieces 0·564″ × 2″.	Breaking Weight.	Elastic Limit.	Elongation.	Contraction of Area.
	Tons.	Tons.	Per Cent.	Per Cent.
Iron with 0·04 per cent. carbon	21·77	14·39	47	76·5
Steel with 1·35 per cent. carbon	57·50	46·53	5	5·6
Iron with 1·37 per cent. phosphorus	28·98	28·98	0	0·0

Crushing Tests.

	20 Tons.	40 Tons.	60 Tons.	80 Tons.	100 Tons.
Iron with 0·04 per cent. carbon	5·80–1·30	25·2–12·8	43·8–30·5	55·3–43·8	62·4–52·2
Iron with 1·35 per cent. carbon	1·30–0·00	3·0–0·0	8·4–0·0	20·0–0·0	33·0–0·0
Iron with 1·37 per cent. phosphorus	0·70–0·00	3·0–0·9	8·9–5·8	20·8–13·6	26·1–23·0

It is a well-known fact that in puddled iron bars phosphorus increases the tenacity, reduces the property of drawing out under tension, and increases the liability to break under shock. It, however, has one good property, as it makes the iron weld easily, iron free from phosphorus being much more difficult to weld than phosphoretic material; but this good property is greatly discounted by the iron at the weld being left in a more or less coarsely granular state and being easily fractured.

Iron containing little or no phosphorus can always be obtained in a fine granular state by heating to about 900° C.,[*] when, no matter how brittle and coarse grained it was previously, its structure will be refined. With phosphoretic iron no such refining follows heating, and the only method of making such material fine in structure is by forging or rolling at a comparatively low temperature; and if the phosphorus is very high, it is very difficult to obtain the fine condition even by forging.

The importance of having a fine granular structure in phosphoretic iron is much greater than in irons and steels containing little of that element.

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[*] It has been shown by (8) Arnold that 1·37 per cent. phosphorus prevents the internal critical change Ar3, about 860° C.

Crystalline Form.

The crystalline structure of irons containing much phosphorus is apparently the same as pure iron. In the drusy cavities of ingots of each there are to be found the fir-tree growths of crystallites of the cubic system. It does not appear that the dissolved phosphide modifies the crystalline form, but possibly when perfectly measurable crystals are isolated, if they ever are, it will be found that the phosphide does cause some slight variation. It is easy to obtain rectangular forms by cleavage from large crystalline grains of iron saturated with phosphide.

There is an increasing tendency, under like conditions of treatment with increasing phosphorus, for iron to crystallise in larger and larger crystalline grains, and I have frequently obtained in fractured metals containing above 1 per cent. phosphorus cleavage faces measuring more than an inch across.

Mr. T. W. Sorby, of Sheffield, very kindly annealed for me, in one of his cementation furnaces, a portion of a metal containing 1·15 per cent. phosphorus. The coarsely crystalline metal was inserted and packed with sand in an iron tube which was closed at both ends with fine clay.

The temperature to which it was subjected must have been about 1000° C., and it was maintained at that temperature for a considerable period. When cold, the appearance was found not to have altered, and, on breaking it to pieces and selecting such external portions as had, in fracturing the metal previous to annealing, broken along three cleavages, leaving corners in projection bounded by three cleavage faces, it was found that, on breaking these, cleavage followed the planes parallel to the faces, proving that the crystalline organisation had not been altered by the prolonged heating, and that there had therefore been no allotropic change to the gamma state.

Hardness.

The hardness of iron is steadily increased with each addition of phosphorus, until, when it is saturated, and contains 1·7 per cent. phosphorus as phosphide, it takes a well-hardened steel drill to drill it properly, and it apparently has a hardness on Mohr's scale of just under 6, probably 5·50; a sharp point will easily scratch apatite, but it is soft enough to be easily scratched by feldspar.

"Heat-tinting" does not give gradation in colouring between the outside and centre of the grains in semi-saturated metals, but strong etching leaves the portions which last solidified relatively darker than the other parts, from which one would conclude that the first portions which commence to crystallise contain less phosphide than the parts last to solidify at the external portions.

The hardness of cementite is between that of feldspar and quartz, or about 6·50°. Massive phosphide of iron appears to have a hardness equal to feldspar, or 6° on Mohr's scale. It is difficult, however, to determine the degrees of hardness, with any accuracy, by means of the existing methods; therefore the figures given must be considered as only approximate.

General Microstructure of Metals of Class I.

The microstructures of all metals of this class are similar, and resemble in appearance similar sections of pure iron, but, generally speaking, the crystalline grains are of greater size and increase with increasing phosphorus. (^{8}) Professor Arnold found that on etching with nitric acid the fluid acted more severely on the junctions of the grains than on their mass, an observation which I have confirmed in many cases, but I have also found that it did not occur invariably. Photo No. 1 is a type of all metals of this class.

Although the microstructure of pure iron and of the metals of Class I. were similar, there were certain characteristic differences.

The polished surfaces of the phosphoretic metals, on being etched with exceedingly dilute nitric acid, were transiently prismatically coloured. The different crystalline grains at the same time assumed different colours, and on a single specimen were to be seen grains coloured yellow, orange, red, purple, green, and blue. They changed rapidly from one colour to the others, and finally the colouring vanished with the continued action of the acid, and a brown stain or deposit was left on the surface, which eventually became quite black.

The black matter could be removed from the surface by slight friction, and acid tincture of iodine partially destroyed it, a reaction which did not follow when the black deposit was formed by etching hardened pure carbon steels. It evidently consisted of the same substance which is left insoluble on dissolving the metals in acid.

CLASS II.

Phosphorus 1·70 per cent. to 10·2 per cent.

In the compounds containing a little over 1·70 phosphorus, the eutectic or pearly constituent, being last to freeze or solidify, is thrown out or expelled from the crystalline grains, and forms fluid boundaries or cells round about them. As the temperature falls these finally solidify, breaking up into two constituents. When cold the polished and etched structure, under low power magnification, has the appearance of an irregular meshed net, the spaces being filled with that part of the crystalline grains of metal which first solidified.

The metal with 1·8 per cent. phosphorus (represented in No. 2 photograph) is an example of this, and somewhat resembles steel containing 1½ per cent. carbon.

When the phosphorus approaches 8 per cent. a pearly constituent occupies the greater area, and on this ground mass skeleton arboriform crystallites abound, consisting of the saturated solid solution of phosphide of iron in iron. (No. 3 photograph represents this compound.)

As 10·2 per cent. is approached these crystallites diminish, and when it is reached the whole mass or area is pearl-like in structure and no crystals are visible. (Photo No. 4.)

All the eutectics of the metallic alloys have not the same appearance or form, but most of those I have examined (and I have examined a very large number) had one common property—that of giving the pearly structure, first discovered by Dr. Sorby in carbon steels after they had been polished and etched by suitable reagents.

The pearly mass with about 10 per cent. phosphorus and 90 per cent. iron is the true eutectic, or the most fusible of the compounds of iron and phosphorus. It has only one melting-point, which is about 980° C.

The melting-points in the metals of Class I. steadily fall with each increment of phosphorus, but each of them has only one solidifying point.

In Class II. the metals intermediate between 1·7 per cent. and 10·2 per cent. show two arrests during their passage from the perfectly liquid to the completely solid condition; the first, when the crystallites fall out of solution; the second, when the eutectic solidifies.

The first arrest is lowered with each addition of phosphorus, the second remains constant throughout the series.

The composition of the hard element of the eutectic was determined by treating the powdered metal with dilute nitric acid. The softer constituent was in this way dissolved away, leaving insoluble the harder constituent.

Prepared in this way, on analysis it was found to contain :—

	1.	2.	Calculated.
	Per Cent.	Per Cent.	Per Cent.
Iron	83·20	83·20	84·42
Phosphorus	15·32	15·48	15·58
Oxidation products, &c. .	1·48	1·32	...
	100·00	100·00	100·00

It is therefore proved that the chemical formula is Fe_3P.

CLASS III.

Phosphorus 10·2 per cent. to 15·58 per cent.

The slightest increase of phosphorus above 10·2 per cent. results in the formation of well-formed crystals and skeletons of crystals of the same chemical composition as the phosphide in the eutectic, and these increase with the phosphorus until, when 15·58 per cent. is reached, the whole mass is composed of them and is homogeneous. (Photos Nos. 5, 6.)

In the metals of this class, as in Class II., there are two arrest-points during solidification.

Each addition of phosphorus raises the initial point of solidification; the final arrest coincides with that of the eutectic, but when about 15·6 per cent. phosphorus is reached, only one arrest-point can be observed, which is about 1060° C.

The microscopic, chemical, and thermal results all tend to prove that the crystals are a definite chemical compound, of the formula Fe_3P.

The metal sections containing the well-formed crystals of Fe_3P have been kindly examined for me by Professor Bauerman, Professor Arnold, and Mr. MacWilliam, who consider that they will most likely prove to be rhombic or oblique.

So far only the *sections of the crystals* have been available for examination, but it is hoped that before long they will be isolated so as to enable the angles to be correctly measured.

In my paper on "The Crystalline Structure of Iron," I gave a photograph of what was believed to be an idiomorphic crystal of carbide of iron.

The metal section photographed contained phosphorus. On re-examination by the heat-tinting process, I found that the crystals believed to be carbide were not so, but were phosphide of iron. I am glad of this opportunity of correcting an erroneous conclusion which any one might have made previous to the discoveries of the method of distinguishing one from the other. Other metallographers would probably find, on re-examining their specimens by the new method, that what they had taken to be cementite was in reality phosphide of iron.

CLASS IV.

Phosphorus between 15·58 per cent. and 21·68 per cent.

When the phosphorus is increased above 15·58 per cent. somewhat porous ingots result, and until 21·68 per cent. is present it is easy to separate the powdered metal into two distinct parts.

On endeavouring to colour or stain the constituents of polished sections so as to identify them by the usual etching methods, no success followed the effort; but on heating them till a blue oxidation temper tint was just visible to the eye, on examination under the microscope two differently coloured parts became evident, one blue, more readily oxidised than the other, and a second which appeared yellow.

Both constituents were practically homogeneous, and were evidently definite chemical compounds. One of these compounds was less soluble in nitro-hydrochloric acid than the other. The more insoluble part was also least readily attracted by the magnet.

The constituent readily coloured blue by heating was the more soluble in acid, and was strongly attracted by the magnet. It consisted of Fe_3P.

The less readily coloured constituent, very slowly acted upon by acids and slightly attracted by the magnet, consisted of Fe_2P.

The microstructure leads one to conclude that the Fe_2P crystallises at a higher temperature than the Fe_3P, for the crystal faces of Fe_2P in the drucy cavities were generally more perfect than those of Fe_3P.

The more insoluble compound, Fe_2P, separated by acid, contained—

	Per Cent.
Iron	78·30
Phosphorus	21·50
Not determined	0·20
	100·00

The compound of iron and phosphorus containing about 18 per cent. phosphorus, which had about equal parts of Fe_3P and Fe_2P, was most fragile and very porous, and the crystals loosely attached to each other were easily separated by slight pressure. On placing the coarse crystalline matter on a steel plate and heating it till some of the particles took a "temper blue colour," and then rapidly cooling the whole, it was easy to pick out the blue particles from those of a pale yellow colour. On testing them chemically side by side, the blue particles were found to approximate to the composition of Fe_3P, the yellow crystals to Fe_2P.

When the mixed mass of blue and yellow particles was approached by a magnet to within a distance of 2 mm., the blue particles were attracted and adhered to the magnet, the yellow ones remaining behind.

The analyses of the magnetically separated compounds were as follows:—

	Magnetic.	Slightly Magnetic.
	Per Cent.	Per Cent.
Iron	84·00	78·40
Phosphorus	15·82	21·50
Not determined	0·18	0·10
	100·00	100·00
Corresponding to the formula of =	Fe_3P.	Fe_2P.

It is not often that compounds can be separated by such simple and diverse methods:—

1st. By chemical reagents.
2nd. By the magnet.
3rd. By heat-colouring and by hand-separation.

Of the three, the magnetic method is by far the most perfect, for whereas Fe_3P is strongly attracted, Fe_2P will not rise to the magnet, and only slightly adheres to it when placed in contact with the finest powder.

CLASS V.

Phosphorus 21·68 per cent. to 24 per cent.

By the expenditure of a very excessive amount of phosphorus and the use of a very high temperature, iron may be made to combine directly with sufficient phosphorus to give a compound containing 24 per cent. of that element. This is contrary to what was found in Dr. Percy's laboratory, where a maximum of 8·46 per cent. was obtained by that method. It is nevertheless an undoubted fact that the higher phosphide can be obtained by direct union.

On polishing the compound so obtained and tinting it by heating, the microscope revealed the presence of two differently coloured constituents. The more easily oxidised was undoubtedly the definite compound Fe_2P, but what the second was has not yet been determined.

SUMMARY OF PART I.

Class I.—Phosphorus, traces to 1·7 *per cent.*—The metals of this class consist of iron containing phosphide of iron, Fe_3P, in solidified solution.

All the metals used commercially, such as wrought iron and steels containing practically no carbon, may be included in this class.

In proportion as the phosphorus is increased, the polished and etched specimens under like acid etching darken relatively with the quantity of phosphorus present.

The dimensions of the grains in solidified ingots, *ceteris paribus*, tend to become larger as the phosphorus is increased, and when about 1 per cent. is present, it is easily possible to get cleavage faces more than an inch in diameter on the fractured material.

Under certain conditions, on annealing metals containing a very large quantity of phosphorus, some of what is in solution will fall out, and separate in the free state as phosphide of iron.

The hardness increases steadily with the proportion of phosphide in solid solution, until, when it reaches a maximum of about 11 per cent., equal to 1·75 per cent. phosphorus, it requires a well-hardened tool to drill it properly.

Probably the great variations in the mechanical properties of phosphoretic material can be explained by the difference in structure, for it has been proved that the same steel or iron can be made very brittle or comparatively tough according to whether the structure has been made fine or coarse.

It is much more important to have a fine structure in phosphoretic material than it is in ordinary steel low in phosphorus.

It is suggested that the study of the mechanical properties of phosphorus irons and steels should be carefully continued, and that observations should be made not only of the chemical analyses and mechanical properties, but of the coincident structure of the samples operated upon, and the best treatment be ascertained which will give the best mechanical properties.

Class II.—Phosphorus 1·7 *per cent. to* 10·2 *per cent.* consists of varying quantities of a saturated solidified solution of Fe_3P in iron and a eutectic containing about 10·2 per cent. phosphorus, which is composed of about 61 per cent. of Fe_3P and 39 per cent. of saturated solution of Fe_3P in iron. (Photos Nos. 2, 3, and 4.)

Class III.—Phosphorus 10·2 *per cent. to* 15·58 *per cent.* contains idiomorphic crystals of Fe_3P, very perfectly formed in compounds containing between 10·5 per cent. and 12 per cent. phosphorus and allotriomorphic crystals, or crystalline grains of the same body, in compounds containing 15 per cent. phosphorus, surrounded by the eutectic containing about 10·2 per cent. phosphorus. (Photos Nos. 5 and 6.)

Class IV.—Phosphorus 15·58 *per cent. to* 21·68 *per cent.*—In the slowly cooled compounds of this class we commence with pure Fe_3P and end with Fe_2P. The intermediate compounds consist of mixtures of the two bodies, easily separated from each other when in powder by a magnet. Fe_3P is readily attracted, Fe_2P very slightly so.

Class V.—Phosphorus 21·68 *per cent. to* 24 *per cent.*—This class has not been sufficiently studied, but it contains two constituents, one of which is Fe_2P.

PART II.

INFLUENCE OF CARBON ON IRON CONTAINING PHOSPHORUS WHEN MELTED TOGETHER.

The study of simple binary compounds is comparatively easy compared with the research relating to compounds containing three or more elements, and in giving the results of a large number of experiments with compounds of iron with carbon and phosphorus, I do not wish it to be supposed that the research has been more than just commenced.

In studying the compounds containing both separated massive carbide and phosphide of iron, existing as they often do side by side, it has been found that the etching methods will not develop indications sufficient to enable the microscopist to tell one from the other. Mr. Osmond and I have independently discovered that the very beautiful method, employed first by Professors Behrens and Martens, which consists of simply heating the polished metals till they are more or less coloured by oxidation, enabled them to do so.* Carbide of iron on heating takes the oxidation tints of straw-yellow, yellow, brown, red, purple, blue, and silver-grey in sequential order. Phosphide of iron passes through the several ranges of colour, but not so rapidly as the carbide.

When a piece of metal which contains carbide and phosphide of iron is heated (by placing it on an iron plate which is heated by a flame under it) until the section assumes an orange colour to the naked eye, and is then rapidly cooled by placing it on a bath of mercury to check further oxidation, on examination under the microscope the carbide will be seen to be red and the phosphide of a pale yellow colour; or if heated till the carbide is blue, the phosphide will be brown or red salmon colour.

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* See Appendix IV.

It requires a little practice to heat the metal to the exact degree, but as the surface is not corroded in any way, if failure follows the first attempt, it is easy to repeatedly re-polish and heat again the same specimen until success is attained.

Objects prepared in this way are not only most valuable, but, owing to the gorgeous colouring, may be classed as very beautiful.

The phosphide is a little softer than the carbide, and when the two bodies are juxtaposed in massive form, polishing removes the former relatively a little more rapidly than the latter, leaving it in relief, but the difference is not sufficiently marked to be of any certain value; and although softer than the carbide, it is too hard to cut or saw with the hardest steel blade.

The Effect of Carbon on Saturated Solutions of Fe_3P in Iron.

In prosecuting this research, the first aim was to ascertain what effect increasing additions of carbon would have upon saturated, or nearly saturated, solutions of phosphide of iron in iron.

In making the trials, a compound was used containing 1·75 per cent. of phosphorus, equal to 18 per cent. of the phosphide eutectic, or about 12 per cent. of phosphide of iron, Fe_3P.

This was effected by melting it with increasing proportions of well-calcined charcoal in magnesia-lined plumbago crucibles. The mixtures were covered with lids of magnesia, consolidated by an admixture of magnesium chloride, and over this a layer of graphite was laid, and finally the crucible was closed with a fire-clay cover, and the mixtures melted in a coke fire.

The results proved that the carbon at the point of solidification throws out of solution a certain proportion of a phospho-pearlite eutectic, the softer constituent juxtaposed with the phosphide consisting of pearlite instead of iron phosphide solid solution.

The proportion so thrown out steadily increases with the carbon. When the carbon is small, the phosphorus eutectic is found at the junctions of the grains more or less completely enveloping them, and surrounding it the pearlite forms most perfect fringes, well illustrated in the two photographs (Nos. 8 and 9), where 1·75 per cent. phosphorus is associated with 0·125 per cent. carbon. With 0·7 per cent. carbon the mass of the grains consists of pearlite, but there still exist areas of the phosphide saturated solid solution. (Photo No. 10.)

As the carbon increases, the amount of the phosphorus eutectic and the pearlite also increase in quantity, until, when about 0·8 per cent. carbon is present, the grains consist entirely of pearlite.

When the carbon is increased to 1·4 per cent. the eutectic of phosphide becomes surrounded by a solid layer of cementite or carbide of iron, which increases in thickness as the carbon is increased. The envelopes of carbide are solid and do not consist of two constituents, whereas the enclosed matter has the usual broken-up duplex character of a eutectic. The white carbide and phosphide appear to run into one another.

When a section of the metal was heated till the eutectic assumed a yellow tint, the cementite borders assumed a fine red colour; it was easy then to see that the carbide was separate from the phosphide at a most clearly marked junction. (Photo No. 11.)

On re-heating it to about 900° C., and allowing it to cool moderately rapidly, the greater mass of cementite was found no longer as an envelope to the phosphide eutectic areas, but now existed as independent cells, cutting up the original large grains of pearlite into a number of smaller grains. The phosphide eutectic retained its original position.

This observation appears to demonstrate that whereas the phosphide eutectic does not diffuse at 900° C., the carbide passes into solid solution at that temperature, and is, on cooling, redistributed between the newly formed pearlite grains. In other words, it behaves in a similar manner to what it does in high carbon steels free from phosphorus. The eutectic, although retaining its original position at 900° C., undoubtedly must have become liquid, for it had altered its character; the two constituents were in a much finer state, and required much higher magnification to see that they were separate.

The following table gives analyses of a series of the metal containing about 1·75 per cent. phosphorus, and various proportions of carbon :—

Nos.	Carbon.	Phosphorus.		
		In Free Fe_3P.	In Solution.	Total.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
1	Nil	Nil	1·75	1·75
2	0·125	0·18	1·37	1·55
3	0·180	0·59	1·18	1·77
4	0·70	1·00	0·75	1·75
5	0·80	1·06	0·70	1·76
6	1·40	1·16	0·60	1·76
7	2·00	1·18	0·55	1·73
8	3·50	1·40	0·31	1·71

These results were obtained on small specimens, rather rapidly solidified. It is probable that if the mass in each case had been greater, and the cooling through the solidifying points slower, the relative proportion of phosphorus thrown out of solid solution would have been different.

The method of determining the free phosphide, although the best at command, gives approximate results only ; but the errors should not exceed 5 per cent. on the quantities given.

It was expected that a larger proportion of the phosphide would have been thrown out of solution by the higher percentage of carbon.

The results are interesting as proving that carbon will not throw the whole of the phosphide into the separate state, that a persistent residuum still remains in solid solution, even although the carbon is as high as 3·5 per cent.

When the carbon is still further increased, a large quantity of massive cementite is present, and an entirely new eutectic is found. The original phospho-pearlite eutectic dissolves a portion of the carbide of iron, which does not separate, but solidifies with it, forming a complex compound mixture, in which thin parallel plates of carbide of iron, cutting up the phospho-pearlite eutectic, are easily detected under the microscope.

This eutectic does not appear to be formed till the carbon approaches 2 per cent.

It is always present in white phosphoretic pig irons. Its exact composition has not yet been determined. A sufficient quantity of the compound free from other elements, such as silicon, manganese, &c., was difficult to obtain, on which to squeeze out the eutectic by hydraulic pressure.

A small quantity of metal yielded a fusible liquate of the following composition, viz. :—

	Per Cent.
Phosphorus	7·05
Carbon	1·30
Iron	91·60
	99·90

This was not pure, and is only given here as representing the approximate composition of the eutectic.

The Effect of Carbon on Iron containing less than the Saturation Proportion of Phosphide Phosphorus when melted together.

When the phosphorus is in much smaller quantity than 1·7 per cent., if the carbon is in sufficient quantity it still causes a separation of phosphide.

An excellent example of this has been afforded by Mr. E. H. Saniter, who discovered in the hearth of an open-hearth basic furnace a piece of partially converted metal which had remained in the bed of the furnace when it was cooled down for relining.

An analysis of this metal yielded in my laboratory :—

	Per Cent.
Carbon (by combustion)	1·230
Manganese	0·450
Silicon	0·060
Sulphur	0·018
Phosphorus	1·380

A portion broken off from the same material yielded the following result by Mr. Saniter's analysis :—

	Per Cent.
Carbon	0·980
Manganese	0·420
Silicon	0·055
Sulphur	0·018
Phosphorus	0·840

These analyses are far from concordant, and are evidence of the great difficulty of obtaining two pieces alike from a mass of metal when large quantities of phosphorus are present and the cooling has been done very slowly. The following remarks, therefore, apply to the specimen supplied to me by Mr. Saniter, about 3 c.m. square.

A portion of this was crushed to coarse powder in a steel-crushing mortar, and determination made of the free and insoluble phosphide, with the following results:—

	Per Cent.
Phosphorus as free phosphide	0·76
Soluble phosphide	0·62

The phosphide of iron was exceedingly brittle, and was located in greatest measure on the outside of the grains, so that on crushing the sample the greater part of it was found in the finer portion of the crushings. These were sieved off, and analysis made of the coarser material left on the sieve.

	Per Cent.
Phosphorus as free phosphide	0·222
Phosphorus as insoluble phosphide	0·606
Total phosphorus	0·828

a result approximating closely to the previous one, and showing that the pearlite grains themselves contained about 0·61 of phosphorus.

The microscope revealed the presence of large crystalline grains of pearlite surrounded by very thick envelopes of what appeared to be massive carbide of iron (cementite). There were also globular-shaped masses of phosphide eutectic surrounded with cementite in the centre of the grains, and idiomorphic crystals of Fe_3P.

The envelopes were not of the character of phosphide eutectics, but were generally massive and homogeneous, excepting at the points where three grains joined together, when they were more or less cut up by inclusions of pearlite.

On colouring the specimen by heat-tinting, the exterior portions of the sections of the envelopes were coloured red, but in the central portion there was seen a thick band coloured pale yellow, a clear proof that the envelope was compound in character, and that it consisted of phosphide of iron in the centre and carbide of iron on the outside. The thickened portions of the envelopes at the junction of three grains, where inclusions of pearlite were present, consisted mainly of phosphide of iron. (Photo No. 13.)

If the mass had been cooled less slowly, there can be no doubt the central portion of the envelopes would have shown the compound structure of the eutectic of phosphorus and iron; but, as is very common in alloys, when the actual mass of the eutectic is small and the cooling very slow, the harder constituent had coalesced or segregated and become massive, whilst the softer portion had been thrown out and united with the greater mass of the surrounding metal.

When this specimen was heated to 900° C., and was allowed to cool in a few minutes from that temperature to 500° C., the envelopes in the polished and tinted section were seen under the microscope to have the true eutectic structure. They were considerably thicker, and occupied more space than the original phosphide areas. The eutectic so formed resembled that in white phosphoretic pig metals.

This complex eutectic is what is always found in white cast iron containing phosphorus.

On breaking a section of the original metal, which had been previously polished and tinted, the line of fracture passed along the phosphide, in the centre of the cell walls.

Mr. Saniter, previous to the systematic micro-study referred to, when he was chemist to the Wigan Coal and Iron Company, having microscopically examined the specimen, and having found that the cell walls were considerably thicker than was justifiable with so little carbon as 0·98 per cent., and knowing that the envelope was much more brittle than the body of the grains of pearlite, he endeavoured, by crushing and sieving, to separate the more easily powdered envelope from the greater bulk of pearlite. Of course, such a crude mechanical process could not be expected to give perfect separation, but, with the assistance of chemical methods in addition, he obtained some most valuable results.

By Mr. Saniter's permission his original results are here given in his own words:—

"As was anticipated on examination under the microscope, it was evident that brittleness was caused by the segregation of a hard substance with the appearance of cementite along the granular junctions. With a view to ascertain its composition the metal was subjected to crushing, and the more brittle portion separated by sieving from the more malleable, that is to say, the intergranular from the granular matter, with the following results, viz.:—

Metal partly crushed and the crushing fractionated by sieving.

- **Would not pass 40-mesh sieve (liner)** = 97·3 per cent. = This was crushed as fine as possible =
  - **Would not pass 80-mesh** 76·5 per cent. This contained—
  - **Passed 80-mesh** 20·8 per cent.
- **Passed 40-mesh but not 80-mesh** 1·2 per cent.
- **Passed 80-mesh sieve** 1·5 per cent.

	Would not pass 80-mesh 76·5 per cent.	Passed 80-mesh 20·8 per cent.	Passed 40-mesh but not 80-mesh 1·2 per cent.	Passed 80-mesh sieve 1·5 per cent.
Carbon	0·64 per cent.			1·10 per cent.
Silicon	0·005 ,,			0·093 ,,
Sulphur	0·014 ,,			0·472 ,,
Phosphorus	0·620 ,,	0·88 per cent.	2·33 per cent.	8·200 ,,
Manganese	0·430 ,,			1·510 ,,
Phosphorus soluble in 1·1 sp. gr. H_2SO_4	=Nil.			0·20 per cent.

"Disregarding the intermediate products, the analysis on the left is that of the pearlite grains, and that on the right of the table the easily crushed intergranular matter. Considering this latter first, the point of most interest is that phosphide as well as carbide of iron is expelled when in excess of a certain point in carbon-phosphorus-iron mixtures, which no doubt accounts for the more injurious effect of phosphorus on steels with high carbon.

"A portion of the intergranular matter was treated with a large excess of 1·1 sp. gr. sulphuric acid for 18 hours in the cold, and the insoluble portion was analysed with the following result:—

	Per Cent.
Carbon	2·07
Phosphorus	10·77
Iron	85·00
	97·84

"This works out approximately to a formula of two molecules of Fe_3P to one of Fe_3C.

"If we examine the eutectic containing 0·64 per cent. carbon and 0·62 per cent. phosphorus, we find that, after allowing for iron to carbon in the ratio $Fe_{24}C$, the composition of ordinary pearlite, the remaining iron is in the ratio $Fe_{25}P$, a figure very interesting, as it is so close to that for the carbon eutectic. This may be only a coincidence, and it would require a considerable amount of investigation before it could be determined whether or not phosphorus forms a similar eutectic to that of carbon with iron. Calculating on these lines, the pearlite grains consist of—

	Per Cent.
$Fe_{24}C$ . . .	71·11
$Fe_{25}P$ . . .	28·77 with a formula 2·6 $Fe_{24}C$, $Fe_{25}P$."

These results of Mr. Saniter, obtained some years before my researches were completed, coincide closely with those obtained at Middlesbrough. The very low carbon, however, which he found in the finely powdered residue may be due to the fact that some of the comparatively coarse carbide plates of the pearlite escaped the sieve.

It is possible that, when there is a considerable quantity of phosphorus present, the pearlite may contain about 0·6 per cent. phosphorus, and the smaller proportion found dissolved in the compound containing 3·5 per cent. carbon given on p. 87 may be owing to the pearlite present representing only about 41 per cent. of the mass.

If the carbon in the pearlite is 0·75 per cent., and that in the massive cementite 6·666 per cent., by calculation the sample with 3·5 per cent. carbon should have the following constitutional analysis:—

	Per Cent.				Carbon per Cent.	Phosphorus per Cent.
Carbide of iron (massive) .	48	×	·0666	=	3·19	...
Pearlite	41	×	·0075	=	0·30	...
Phosphide of iron (free) . .	9	×	·1556	=	...	1·40
„ „ (dissolved) .	2	×	·1556	=	...	0·31
	100·00				3·49	1·71

The pearlite would in such a case contain 0·75 per cent. instead of 0·60 per cent. of phosphorus. If, however, we remember that in one case the metal was cooled very much slower than the other, it may account for the difference.

It is satisfactory in so far as the calculation gives about the same amount of dissolved phosphide as was actually found in the metal containing 1·77 per cent. phosphorus and 0·80 per cent. carbon, and which consisted of pearlite and no free massive carbide. The amount in solid solution varied according to the condition of solidification, and discredited the hypothesis that there exists a definite chemical compound of the chemical formula $Fe_{25}P$.

In order to ascertain what would result if Mr. Saniter's sample was decarburised by heating with ore in a furnace for the manufacture of malleable castings, a portion was inserted inside of a wrought iron tube, and was packed with fine scale from a wire-rolling mill. The ends of the tube were closed with fireclay, and the whole was then passed through a furnace with the ordinary charges. When cold, it was found that a considerable quantity of the scale had been reduced to the metallic state and adhered very strongly to the metal. On analysis the following interesting results were obtained:—

	Before. Per Cent.	After. Per Cent.
Phosphorus	1·38	0·91
Carbon	1·23	traces
P in Fe_3P (free)	0·76	0·18
,, (solution)	0·62	0·73

The loss of phosphorus in the conversion, amounting to 33 per cent. of the whole, was sufficiently startling to merit a searching investigation.

In Part I. analyses are given showing the result of decarburising a piece of metal containing 1·8 per cent. phosphorus and 0·18 per cent. carbon. In that case the micro section resembled No. 9 Photo. The phosphide areas were not continuous, but terminated in obtuse points. Where there was direct connection between these eutectic processes and the outside of the metal, the eutectic simply ran out leaving cavities. Had the eutectic been continuous and connected throughout the whole piece, probably much more would have escaped in that way. In the sample in which so much greater quantity of phosphorus had disappeared, the large crystalline grains were entirely enveloped with phosphide and carbide of iron, and were continuous like the cells of a honeycomb. As soon as a temperature of about 980° C. was reached, these envelopes or cells would combine with a portion of the metal in the adjoining grains to form a fusible liquid eutectic. This must have run out of the sample, and the grains falling together as the supporting cells flowed away, united to form a homogeneous whole. The micro sections in this case showed no empty spaces; no cementite or phosphide enveloped the grains; but on polishing on parchment, broad reticulated bands, corresponding to the original positions of the cells, remained bright long after the intercell structure had become tarnished, showing the existence of parts more highly charged with phosphorus in the regions where the free phosphide had originally existed. Etching with acid and heat oxidation all confirmed that conclusion. It is evident, then, that some of the phosphide had diffused into the grains, but had not penetrated to any great distance. The amount actually so diffused is shown by the analysis to be 0·11 per cent. In one or two parts of the section comparatively large solidified "pools" of the eutectic were located, thus accounting for the free phosphide found by analysis. The same pools or areas of massive segregations were present in the original metal and were generally located at the junctions of several grains, and it appears reasonable to conclude that the surrounding metal under such conditions could not fall in and join together, and so force out the liquid eutectic; it would, therefore, remain imprisoned at the very time during which the portions of the eutectic between the granular faces were flowing out of the metal.

If, then, the eutectic was actually expelled, it should be found in the scale in which the metal was packed. Fortunately a portion of this had been reserved. It was tested together with a portion of the scale before it was packed in the tube. The following results were obtained:—

	Before. Per Cent.	After. Per Cent.
Iron	74·6	96·3
Phosphorus	0·06	0·24

The quantity actually used was considerable. No record was kept of the relative weights of the metal and scale, so that it is impossible to make a balanced account of the phosphorus.

The fact, however, that the phosphorus in the scale was greatly increased is strong proof that it had obtained it from the metal.

One other interesting observation was made on the sample. It was noted that the metal immediately adjoining the scale, 1 m.m. in thickness, behaved under the action of acids almost like pure iron. It did not darken on digesting with dilute acid, whereas the whole mass below became soot-like in appearance. The only explanation possible is, that after the carbon had reduced the scale to the metallic state, a portion of the phosphorus actually diffused into it from the outer crust.

The question still not satisfactorily settled at this stage is, Does the carbon in commercial steels, amounting to about 0·9 per cent. and above that quantity, when solidifying from the liquid state cause the phosphide present to be thrown out of the solution ?

To answer that question, a steel containing 1 per cent. carbon and only 0·02 per cent. phosphorus was melted in several portions, with increasing doses of phosphide of iron sufficient to give from 0·06 per cent. to 0·24 per cent. phosphorus.

To effect this, and at the same time to ensure strictly comparative results, a large plumbago crucible was filled with plastic magnesia. With a cork-borer cylindrical prisms of the magnesia filling were removed at equal distances near to the sides of the crucible, leaving in this way a series of vertical holes. The crucible so prepared was heated to dry the magnesia, and into the four holes weighed quantities of steel and phosphide were introduced. The holes were then plugged with magnesia stoppers, a covering of plumbago applied, and over all a crucible lid. It was then placed in a hot-wind furnace, and after an hour the fire was allowed to cool down slowly so as to retard the solidification. When cold, the metals were removed and weighed to ascertain whether there had been any gain or loss. For comparison, one of the pieces of steel which was melted had not any phosphide added to it. The following results were obtained :—

					Weight.		
	Steel. Grammes.	Phosphide.		Phosphorus.	Before.	After.	Loss or Gain.
No. 1 . .	11·810	None	=	0·02	11·810	11·814	+0·004
No. 2 . .	13·070	0·050	=	0·06	13·120	13·120	Nil
No. 3 . .	12·950	0·100	=	0·11	13·053	13·048	0·002
No. 4 . .	11·630	0·200	=	0·21	11·830	11·830	Nil

ANALYSES OF METALS.

	Carbon.	Phosphorus.
No. 1	1·05	0·020
No. 2	1·06	0·058
No. 3	1·05	0·118
No. 4	1·06	0·245

MICRO-STRUCTURE.

No. 1 was slightly meshed with cementite, but no phosphide could be detected.

No. 2 was more meshed than the last, and phosphide of iron was visible after heat-tinting.

No. 3 was more meshed than the last, and a greater proportion of phosphide was visible.

No. 4 had phosphide in strong evidence.

Although the phosphide was in strong evidence judging from the appearance, only a very small proportion of the whole seemed to be in the free state. In the case of No. 4, if all had separated there would have been about 3 per cent. of the eutectic visible, whereas probably not more than one-third of that amount was really present. A further trial was made on a larger scale, but in this case a charge of about 50 lbs. of molten steel was poured successively into five different small fireclay moulds. After the first mould was filled a stick of phosphorus was dropped into the fluid steel in the crucible, where it rapidly dissolved. After mixing a second mould was filled. A second stick of phosphorus was then added to the crucible and a third mould filled. After each mould was filled a further addition of phosphorus was made to the remaining steel till all the five moulds were filled.

The analyses of the steels when cold were as follows:—

Nos.	Carbon.	Phosphorus.	Phosphorus in Free Phosphide.
	Per Cent.	Per Cent.	Per Cent.
1	0·95	0·037	Nil
2	0·96	0·099	0·002
3	0·95	0·122	0·035
4	0·96	0·347	0·065
5	1·02	0·548	0·163

No free phosphide could be detected by the microscope in No. 1. In No. 2 it was doubtful if any was present. No. 3

contained traces. Nos. 4 and 5 contained distinct quantities. No. 5 ingot was very red-short, and broke to pieces with the first blow of the hammer.

It seemed reasonable to believe that just as the pearlite in the highly phosphoretic metals dissolves and retains in solution 0·60 per cent. phosphorus, so a pearlite steel would not throw off free phosphide till that amount was exceeded. The above results prove, however, that this is not the case. Steel with about 1 per cent. carbon, in solidifying, does evidently throw off a portion of the dissolved phosphide, even although the proportion of phosphorus is only 0·06 per cent.

The rate at which it solidifies appears to influence the result, for in the laboratory experiments, when solidification was retarded, more free phosphide separated than in the trials in which it was unavoidably accelerated.

It was noted that just as high phosphorus carbonless irons in the state of drillings dissolved in dilute sulphuric and hydrochloric acids more rapidly than those containing little, so the carbon steels containing phosphorus dissolved much more rapidly than the same material containing practically none.

Five grammes each of the drillings from the five steels above mentioned, on placing in mixtures of 20 c.c. strong sulphuric acid and 250 c.c. of water, dissolved at very different rates.

No. 1, containing practically no phosphorus, took ten hours to completely dissolve, whereas No. 5, with 0·548 per cent. phosphorus, was dissolved in two hours. The other steels passed into solution in periods intermediate between the two extremes.

A dark soot-like residue was left behind, the proportion appearing to coincide with the quantity of phosphorus present.

Many commercial structural steels containing between 0·10 per cent. and 0·6 per cent. carbon, have been examined, but in no case have I detected free phosphide of iron, even when the phosphorus exceeded 0·1 per cent. This is what would be expected, for in such partially carbon saturated irons there is more or less free ferrite, and this strong solvent for phosphide would retain it in solid solution.

It is highly probable, judging from the behaviour of dilute acids upon steels, more or less highly charged with carbon, that the carbon causes the phosphide to be concentrated either in the massive ferrite or in the ferrite of the pearlite, or in both.

Before discussing this question, reference must be made to the valuable results given by (14) Messrs. Osmond and Werth.* These gentlemen, on treating various metals, irons, and steels with hydrochloric acid under the same conditions, found that the proportion of the phosphorus given off as phosphine gas (PH_3) varied with the amount of carbon present. I cannot do better than give a short abstract from their most valuable paper. The phosphine evolved was absorbed in an ammoniacal solution of silver nitrate.

"We have determined the quantity of Ag reduced, *i.e.* the proportion of PH_3 evolved by a series of very different products, passing the gas first through an ammoniacal solution of $CdSO_4$, where H_2S is absorbed.

"Appended are the results obtained on dissolving 4 grammes of each metal in 35 c.c. concentrated hydrochloric acid and gradually heated until completely attacked:—

Material.	Analysis.					P. Evolved as PH_3. per 100 Samples.	Parts per 100 P. as PH_3.
	C.	Mn.	Si.	T.	P.		
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Acid Bessemer Steel—							
Before the addition of spiegeleisen	...	...	...	...	0·065	0·044	68
After such addition	...	...	...	...	0·065	0·028	43
Basic Bessemer Steel—							
Before the addition of spiegeleisen	...	...	...	0·038	0·046	0·030	65
After such addition	...	...	...	0·022	0·046	0·018	39
Open-hearth Steel—							
Before the addition of spiegeleisen	...	...	...	...	0·033	0·022	67
After such addition	0·49	0·37	0·075	0·024	0·041	0·014	34
Hardened	0·49	0·37	0·075	0·024	0·041	0·013	32
Very soft steel	0·18	0·10	...	0·060	0·070	0·049	70
"Diamond" steel No. I.	1·17	0·18	0·44	0·018	0·033	0·005	15
Ordinary Bessemer steel	0·50	0·57	0·11	0·042	0·065	0·030	46
Ordinary Bessemer steel	0·49	0·74	0·23	0·022	0·065	0·026	40
Pig iron	...	...	...	...	0·055	0·041	38
Burnt iron from the Moselle, in pseudo-crystals	0·11	trace	0·058	0·032	0·810	0·147	18
Spiegeleisen	4·00	19·84	...	...	0·145	0·004	3
Basic Bessemer pig iron	3·00	2·16	1·71	0·13	2·500	0·037	1·5
Forge pig iron	3·00	0·07	1·37	0·48	1·750	0·038	2·2

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* *Theorie Cellulaire*, Mem. de l'Artillerie de la Marine, 1887, vol. ii. p. 273.

The authors remark:—

"This table clearly shows that there is no relation between the total P and that freed as PH_3. The latter depends entirely on the percentage of carbon; indeed, more phosphoretic metals only allow an insignificant amount of PH_3 to be evolved, whilst soft (mild) irons and steels evolve under the same circumstances comparatively important quantities, the same steel giving more PH_3 after decarburisation than after recarburisation. Manganese is without effect seeing that spiegeleisen and Moselle iron behave after the same manner.

"The quantity of PH_3 evolved also varies, all other conditions being equal, with the strength of the acid.

"A fraction of the P then seems to be combined with the iron, with which it forms a phosphide partially decomposed by HCl, whilst the surplus is engaged in a complex combination with the carbon of annealing cement carbon."

Weyl's method gave identical results.

"If we treat the P in the residues which this method separates, we find in the sample containing:—

	Per Cent.
Carbon	0·490
Silicon	0·075
Sulphur	0·024
Phosphorus	0·041
Manganese	0·037

Steel.	Forged and Carefully Cooled (Chilled).	Forged and Annealed.	Tempered in Cold Water.	Tempered and Annealed.	Average.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Dry residue per 100 parts steel	3·310	4·110	1·620	4·140	...
Phosphorus treated per 100 parts of dry residue	0·840	0·640	1·940	0·760	...
Phosphorus calculated on 100 parts of steel	0·028	0·026	0·031	0·031	0·029

	Per Cent.	Per 100 P. Per Cent.
Average of same steel (P)	0·041	67
Liberated as PH_3	0·0135	33"

These results are most instructive, and have been fully confirmed by my own researches.

I have failed to meet with any steel containing much carbon which yielded more than a small fraction of the phosphorus in the state of PH_3, and on the other hand from steels low in carbon the preponderating proportion of the phosphorus passed off as that gas on dissolving them in strong hydrochloric acid.

Baron Jüptner also, in his researches, shows that in high carbon metals only a very small proportion of the total phosphorus passes off as PH_3. He does not, however, appear to have examined steels with more than 0·30 per cent. carbon.

The following table gives Baron Jüptner's results, and in addition the percentage proportion of phosphorus given off as PH_3, which I have calculated from them, viz.:—

No.	Carbon per Cent. by Weight.	Phosphorus per Cent. by Weight.	Phosphorus per Cent.		Remarks.
			Parts per 100 Sample, as PH_3.	Parts per 100 P, as PH_3.	
					A. *Pig iron.*
1	2·385	0·1315	0·0263	2·00	White pig iron.
2	3·418	0·0744	0·0026	3·5	Dark grey pig.
3	3·418	0·0744	0·0058	7·8	Dark grey pig, dissolved in sulphuric acid diluted with equal volume of water.
4	2·296	1·048	0·0383	3·6	So-called "Panzerguss" for fire-bars.
					B. *Wrought iron and steel.*
5	0·2254	0·0970	0·0054	5·50	Short.
6	0·1800	0·0596	0·0020	3·30	Short.
7	0·1510	0·0690	0·0012	1·71	Short.
8	0·239	0·1010	...	...	Good material.
9	0·259	0·0860	0·0015	1·70	Good material.
10	...	0·0964	0·0162	16·00	Very short.
11	0·273	0·0469	0·0054	11·00	Slightly cold-short.
12	0·308	0·1242	0·0243	20·00	Cold-short.
13	0·343	0·5649	0·0248	4·0	Cold-short.
14	0·122	0·6212	0·0190	3·0	Cold-short.
15	0·375	0·0847	0·0171	20·0	Increasing in cold-shortness.
16	0·217	0·0677	0·0184	27·0	
17	0·168	0·0704	0·0177	25·0	
18	0·137	0·0648	0·0218	32·0	
19	0·220	0·0829	0·0218	26·0	
A	0·110	0·442	0·355	80·33	Welds easily. Very great cold-shortness.
B	0·123	0·456	0·289	63·35	Welds easily. Great cold-shortness.

The actual tests made in a testing-machine of A and B samples were as follows:—

	A	B
Tensile strength, tons per square inch . .	27·00	22·40
Elongation on 50 millimetres, per cent. . .	8·40	12·00
Induction in area, per cent.	29·32	25·60

The proportion of phosphorus as PH_3 given off after the samples were annealed and hardened in water was—

83·13 per cent. in A, and 68·75 per cent. in B,

an increase of about

3 per cent. in A, and 5 per cent. in B.

The results show generally that when the phosphorus is high, little PH_3 is formed. Nos. 12 and 13 are notable instances of this. The observations of Osmond and Werth, Baron Jüptner, and myself agree in this respect. The proportion evolved from the low carbon steels in the Baron's experiment, however, is very different to the result of the other observers. Possibly the steels may have been of a unique character, and we may not have met with any of the same kind, or possibly the methods employed may have been responsible for the great discrepancies. It may be accepted, however, that when working in the manner described by Messrs. Osmond and Werth and myself, the carbon has an important influence generally in preventing the formation of PH_3 when steels containing phosphorus and carbon are dissolved in acid.

It is important to ascertain why that should be.

The answer to that question appears at present to be beyond the region of direct experiment, and one is obliged to endeavour to reason by induction, basing hypothesis on known facts.

It has been shown in Part I., that as the phosphorus becomes more and more concentrated, the quantity of phosphine evolved correspondingly decreases. There is no evidence that phospho-carbon compounds are produced or have existence. All evidence negatives such a supposition.

It is most probable that in steels containing carbon and phosphorus, when in the fluid state, there exists a compound solution intimately mixed, one of carbide, the other of phosphide of iron in iron, and that the carbide solution is the more persistent, taking what iron it requires, leaving what is in excess for the phosphide, which forms a more or less concentrated solution with it, the extent of the concentration depending on the quantity of carbon present. When the steel solidifies, the two solutions become solid solutions. On cooling through Ar1, the carbide separates, leaving ferrite, and ferrite more or less saturated with Fe_3P.

This conclusion is in conformity with the admitted fact that phosphorus is more embrittling in high carbon steels than it is in those with less carbon. If free phosphide is liberated, as it has been proved it is with 0·06 per cent. phosphorus and about 1 per cent. carbon, as it forms meshes round the grains, it must materially reduce the strength of the mass. If the phosphide is concentrated in a part of the iron when the carbon is lower, say between 0·5 per cent. and 0·8 per cent., that part of the structure is likely to be more liable to give way easily under sudden stress than if it was not so highly charged with phosphorus.

It must not be at this stage concluded that because generally the higher the carbon the less PH_3 is given off, and *vice versa*, that it always is the case. Possibly variations in the rate at which the liquid steels are cooled, and in the manner it is heated previous to forging, and also whether or not it is annealed, may have influence in determining in what condition of concentration the phosphide remains in the finished steel.

This section of the subject is worthy of most serious research, and it is to be hoped that the chemists in the many steelworks throughout the world will endeavour to clear away the darkness which surrounds this very complicated branch of the subject.

The hypotheses advanced at the present stage of the research can only be tentatively held, and it is not desired that they should be accepted as revealed facts.

Does Quenching Steel after Heating to High Temperatures affect the Phosphorus Condition?

(18) E. D. Campbell and S. C. Babcock have made certain investigations to determine whether or not the phosphorus condition is different in the same carbon steel when it is annealed and hardened. The method employed consisted in dissolving the steels in slightly acid solution of mercuric chloride, and determining the amount of phosphorus which remained in solution. The results obtained were as follows:—

The analyses of the three steels experimented upon are as follows:—

	1. Per Cent.	2. Per Cent.	3. Per Cent.
Carbon	0·100	0·37	1·22
Phosphorus	0·119	0·16	0·098
Manganese	0·484	0·82	0·780
Sulphur	...	...	0·068
Silicon	...	...	0·058

The following proportions of phosphorus were made soluble after varying thermal treatment:—

No. 1. *Steel Carbon* 0·10 *per cent.*

	Phosphorus on 100 of Sample. Per Cent.	On 100 of Phosphorus. Per Cent.
Annealed	0·099	83·2
Heated to 719° C. and quenched	0·081	68·08
,, 825° ,,	0·079	66·4
,, 928° ,,	0·080	67·2
,, 1028° ,,	0·086	72·2

No. 2. *Steel Carbon* 0·36 *per cent.*

	Phosphorus on 100 of Sample. Per Cent.	On 100 of Phosphorus. Per Cent.
Annealed	0·137	85·6
Heated to 728° C. and quenched	0·110	68·8
,, 827° ,,	0·066	41·2
,, 923° ,,	0·048	30·0
,, 1027° ,	0·049	30·6

No. 3. *Steel Carbon* 1·22 *per cent.*

	Phosphorus on 100 of Sample. Per Cent.	On 100 of Phosphorus. Per Cent.
Annealed	0·098	100·00
Heated to 719° C. and quenched	0·087	89·8
,, 750° ,,	0·051	52·0
,, 825° ,,	0·018	18·3
,, 923° ,,	0·015	15·3
,, 1023° ,,	0·016	16·2

These results are very instructive, but vary somewhat from what would be anticipated from what has preceded, for it would appear that the phosphorus is more soluble, in the special reagent used, in high carbon steels than in those containing little. The authors, however, are of the opinion that much remains to be done before we shall be able to draw reliable conclusions as to the forms in which phosphorus may exist in iron and steel, the conditions under which the different forms are produced, and the influence of the different forms on the physical properties of the metals.

I intend, as soon as time will permit, to work with the method described by those gentlemen, and shall communicate the results at a later date. The conclusion they apparently have arrived at is, that varying carbon condition in a steel is coincident with varying phosphorus condition.

On the Effect of Carbon introduced into Phosphoretic Iron by the Cementation Process.

(4) Behrens and Van Linge, in studying the constitution of Dannemora cemented bar containing only 0·02 per cent. of phosphorus, found that the phosphide separated with the carbide, and according to (11) Baron Jüptner, they found that the phosphide was inside the carbide. On consulting the original paper, it would appear that on dissolving the cement bar, the authors found some phosphorus associated with the insoluble carbide, and calculated that if the whole of that element existed as Fe_8P there should have been about 0·2 per cent. insoluble.

It appeared to me that bars with so little phosphorus as 0·02 per cent. were not the best upon which to determine the reactions which take place in the cementation furnace. With the most valuable assistance of Mr. T. W. Sorby of Sheffield, without whose aid no practical results could have been obtained, I have had many pieces of phosphoretic bars, &c., carburised by cementation, and these were carefully examined.

The first sample, for which I am indebted to Mr. A. Cooper and Mr. C. H. Ridsdale, consisted of a piece of iron taken from metal during the afterblow in a basic converter, when about 0·6 per cent. phosphorus remained.

A second sample consisted of a piece of puddled bar containing about 0·5 per cent. phosphorus.

The following are the analyses after carburisation :—

Basic Iron (Cemented).

	Per Cent.
Carbon	1·16
Phosphorus	0·63
Phosphorus as free phosphide	0·02
Phosphorus in solid solution	0·61

The microscope proved that, except at the external parts, no free phosphide was present. The carbon being highest in that region, it was natural to expect free phosphide there if anywhere.

Puddled Bar (*Cemented*).

This sample was far from homogeneous, and had blistered slightly. It had the following analysis:—

Description.	Carbon.	Phosphorus.		
		Total.	As Free Fe_3P.	In Solid Solution.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Outside layer, 3 m.m.	1·35	0·495	0·054	0·441
Second layer, 6 m.m.	0·96	0·490	0·028	0·462
Third layer, 9 m.m.	0·75	0·500	Nil.	0·500

It will be seen that, excepting near the outside where the carbon is in greatest quantity, practically no phosphide had separated.

The microscope exactly confirmed the chemical analysis.

These two metals were then melted in magnesia crucibles and cooled slowly, in order to find how much phosphide would separate during solidification. The following results were obtained:—

Description.	Carbon.	Phosphorus.		
		Total.	As Free Fe_3P.	In Solid Solution.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Basic iron	1·16	0·63	0·27	0·36
Puddled bar	1·10	0·50	0·21	0·29

In the next trial a piece of metal containing 1·96 per cent. phosphorus was experimented upon. It was of very irregular shape and about 6 c.m. in diameter at the thickest part. When it came out of the cementation furnace, it was much scored on the outside, as if fluid metal had been run over it in thin streams. The lower part had adhering to it a solidified drop of metal, which had evidently liquated from the specimen. It was detached for analysis. On fracturing the metal, a most instructive structure was revealed. (Photo No. 19.)

The metal before treatment was coarsely crystalline, with cleavage faces 3 c.m. across. After carburisation, excepting in a small kernel where the metal had escaped carburisation and where the original structure remained intact, the metal was entirely altered.

The external parts of the structure were coarsely granular, but between these and the kernel the crystalline masses were arranged in columns clearly illustrated in the photograph.

Portions were taken from fixed positions, and these were separately analysed with the following results:—

Description.	Carbon.	Phosphorus.			
		Total.	As Free Fe_3P.	In Solid Solution.	Lost.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Kernel, centre . . .	traces	1·96	0·94	1·02	None
Do. average . . .	0·23	1·94	0·94	1·00	None
1	0·89	1·52	0·86	0·66	0·42
2	0·93	1·30	0·61	0·69	0·64
3	1·20	1·05	0·38	0·67	0·89
4 external layer . .	1·31	0·91	0·29	0·62	1·03

The drop of metal from the bottom of the piece contained

Phosphorus . . . . 4·86 per cent.

The evidence is conclusive that, as the carbon passed into the metal, its dominating influence threw out the phosphide, equivalent to all excepting about 0·65 per cent., and in doing so produced sufficient gamma iron to effect a complete rearrangement of the structure. The liquid phospho-carbide eutectic thrown off to the boundaries of the grains, being continuous and extending to the exterior, simply liquated away.

As the carbon passed into the beta iron containing the solid solution of phosphide, an allotropic change under the influence of the carbide must have been gradually effected, and coincident with that change a reorganisation of the crystalline structure. The crystalline development must also have been gradual, growing steadily from the exterior to the centre, coincidentally with the penetration of the carbon. White iron, zinc, and other metals crystallise in similar radial columns on casting in cold moulds, when the change of state proceeds from the cold surfaces towards the centre.

The change from the allotropic condition of beta to that of gamma iron, although both are in the solid state, is almost as violent as when the metals above referred to changed from the liquid to the solid condition.

(17) I have elsewhere shown that when steel containing carbon is decarburised at a temperature under 800° C., a similar columnar structure is developed in the solid metal, but in that case the gradual crystalline growth, although from the exterior to the interior, is caused by an allotropic change in the iron from the state of gamma to beta iron, exactly the reverse of what took place in the cementation furnace.

Microstructure of Cemented Metal.

A section of the metal revealed a most instructive structure when examined under the microscope. The central part, where there was no carbon, was traversed and cut up by plates or prisms of free phosphide of iron, and resembled the same metal after it left the malleable casting-furnace, illustrated by Photo No. 20, a coincidence which removes the supposition that oxidising influences were responsible for the reorganisation of the phosphide from the condition in which it existed in the metal before treatment. Near to the junction between the kernel and the columnar grains, the eutectic was bordered with a beautiful fringe of pearlite. The cementite laminæ radiated from the junction towards the centre, the base of which rested upon a layer of the phospho-pearlite eutectic. The kernel was more or less spherical, and was surrounded by a shell of the same eutectic. This brittle envelope made it easy to break away the surrounding metal, leaving the kernel intact. The radiating columnar masses were encased by a layer of the phosphide eutectic, and the latter was surrounded by a toothlike formation of cementite. The mass of the columns consisted of pearlite in which were embedded oval, elliptical, and globular masses of the eutectic, some of which were encased by cementite. The amount of the phosphide eutectic decreased with the distance from the centre. The columnar structure terminated at a distance of 1½ centimetres from the centre, and was replaced by ordinary polygonal grains, the joints of which contained very little phosphide, but sufficient carbide to completely envelop them. Imprisoned in the centre of these grains were globular masses of eutectic, and at wide distances apart irregular-shaped masses of the same substance were segregated at the junction of three grains.

The consideration of these observations leads to the following conclusions:—

That as the carbon diffused into the mass in a forward direction, the phosphide eutectic fell out of solution in the rear, and at first the liquid eutectic so formed would be thrown entirely out of the metal and escape. As the carburisation progressed, the metal in the rear would change its allotropic state from beta to gamma iron, and would recrystallise into the well-known polygonal grains. In front of these a layer of fluid eutectic would continually be forming, but it would, as rapidly as it was formed, flow backwards along the crystalline junctions to the outside of the metal, leaving a residuum behind. The grains at first formed would in all probability be smaller than if they were left in the metal when cold, but under the long-continued action of heat would rearrange their crystalline orientation and fall together so as to form a smaller number of larger grains or columns; but in doing so the intervening eutectic could not be completely expelled, and would remain imprisoned more or less completely, and not having any free passage to escape, would at once begin to coalesce, forming at first oblong drops, which in course of time would contract to the forms more or less globular, actually present in the cold specimen.

If the specimen carburised had been perfectly globular and the carburisation regular at all times during the process, there would have been a spherical fluid area between the centre and the outside, dividing a globe of solid metal in the middle from a solid shell at the exterior, more or less cut up by fluid cells through which the liquid eutectic would continually flow, and which would eventually leave the mass of metal and fall into the charcoal surrounding it. Although the specimen was not globular, the fluid envelopment must have been developed and continual liquidation of the eutectic been effected.

These interesting inductions are fully justified by the observed facts and data obtained during many years' study of metallography, and is another instance of the valuable aid the microscope can give in the study of metallurgy.

Does Phosphorus in Iron Limit the Amount of Carbon capable of being Taken up in the Iron?

That question has been answered in the affirmative by the less carbon invariably found in corresponding grades of Bessemer, Cleveland, and other phosphoretic irons.

The following comparative average analyses of East Coast hæmatite and Cleveland pig irons show a difference of about 0·35 per cent. carbon less in the phosphoretic iron:—

	Number 1 Brand.	
	Hæmatite.	Cleveland.
	Per Cent.	Per Cent.
Combined carbon	0·15	0·12
Graphite	3·95	3·63
Manganese	0·85	0·75
Silicon	2·80	2·80
Sulphur	0·03	0·03
Phosphorus	0·04	1·56

The 1·56 phosphorus in the Cleveland iron is equivalent to close upon 10 per cent. phosphide of iron. If this was deducted, the remainder would contain—

4·16 per cent. total carbon, against
4·10 per cent. in the hæmatite.

Basing our calculations on the assumption that it is the Fe_3P which monopolises the iron, and prevents it combining with carbon under the conditions which reign in the blast-furnace, we find by calculation that with pure iron on the one hand, and pure phosphide on the other, the carbon capable of being taken up would be about 4·6 per cent. in the pure iron and none in the phosphide, and that the carbon in the metals intermediate between the two extremes would depend on the phosphide present in them.

The following table will make this clear:—

Pure Iron.	Phosphide.	Phosphorus.	Carbon, Calculated as Capable of being Absorbed.
Per Cent.	Per Cent.	Per Cent.	Per Cent.
100	None	None	4·60
75	25	3·89	3·45
50	50	7·78	2·30
25	75	11·67	1·15
None	100	15·58	None

In order to ascertain if the result of actual experiment would coincide with the calculated results, mixtures of phosphide and pure iron were made so as to approximate to the above proportions of phosphorus and iron, and these were melted side by side in a charcoal brasqued crucible containing five separate compartments. The heat was regulated so as not to exceed the temperature of the blast-furnace, and was certainly not high enough to melt pure iron.

The analyses of the products were as follows, viz.:—

Analysis of Mixture.		Carbon in Melted Metals.	Fracture.
Iron.	Phosphorus.		
Per Cent.	Per Cent.	Per Cent.	
100	None	4·15	White
96	4·10	3·25	,,
93	7·90	2·00	,,
87	13·00	0·70	,,
83	16·00	Nil.	,,

The results, although deviating from what was calculated, nevertheless are sufficiently close to show that the basis on which the calculations were made is fairly correct. It is well known that even from the blast-furnace the No. 1 pig irons will vary very considerably in carbon, from causes not at present fully understood. The temperature, however, *ceteris paribus*, undoubtedly has the greatest influence in determining the differences.

A second series of comparative trials were made with phosphoretic metals of known phosphorus content by carburising in the manner above described, but at a lower temperature than in the previous trial, with the following result:—

Phosphorus in Metals. Per Cent.	Carbon in Carburised Metals. Per Cent.
1·85	3·50
4·17	2·50
6·03	1·50
10·15	0·65

Here the total carbon is much less than in the previous records, but the influence of the phosphorus in preventing the absorption of carbon is manifest.

All of these metals were free from graphite, even the first sample containing only 1·85 per cent. phosphorus.

A most interesting metal actually produced in an East Coast blast-furnace many years ago, before the value of basic slag was recognised, was made on blowing out the furnace with basic slag instead of limestone. The analysis of this metal was as follows:—

	Per Cent.
Iron by difference	64·927
Combined carbon	traces
Graphite	Nil.
Manganese	4·550
Silicon	0·396
Sulphur	0·050
Phosphorus	17·910
Vanadium	1·711
Chromium	0·446
	100·000

That the heat was great is evidenced by the large quantity of manganese, vanadium, and chromium which were reduced, yet the carbon was practically absent—a convincing proof that phosphorus in sufficient quantity prevents carbon from retaining its combination or from making any union with the iron, in which respect it closely resembles the effect of 20 per cent. silicon.

Does Phosphorus in Iron tend to Prevent the Separation of Graphite and Produce White Iron?

This question has often been asked, but practical experience with furnaces making hæmatite and phosphoretic Cleveland irons has shown that 1·5 per cent. of phosphorus, at any rate, has no influence in preventing the separation of graphite.

A careful observer can, however, note a difference in the greyness of equally open highly phosphoretic pig iron and one practically free from phosphorus; but this is not caused by the presence of combined carbon, but is due to the fact that the free phosphide present gives a white fracture, and that the two irons contain different quantities of graphite. The combined carbon is about equal in each.

In order to ascertain the effect of large quantities of phosphorus in presence of silicon, mixtures of silico-phosphide of iron and iron in various proportions were melted in charcoal-lined partitioned crucibles. The temperature was very intense, certainly higher than that of the blast-furnace. The results were as follows:—

	1.	2.	3.	4.	5.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Combined carbon .	1·10	0·56	0·11	Nil.	Nil.
Graphite . . .	2·62	1·73	1·88	1·69	0·83
Silicon	0·92	1·96	1·96	2·84	3·36
Manganese . . .	traces	traces	traces	traces	traces
Phosphorus . . .	0·21	4·95	6·85	8·35	12·86

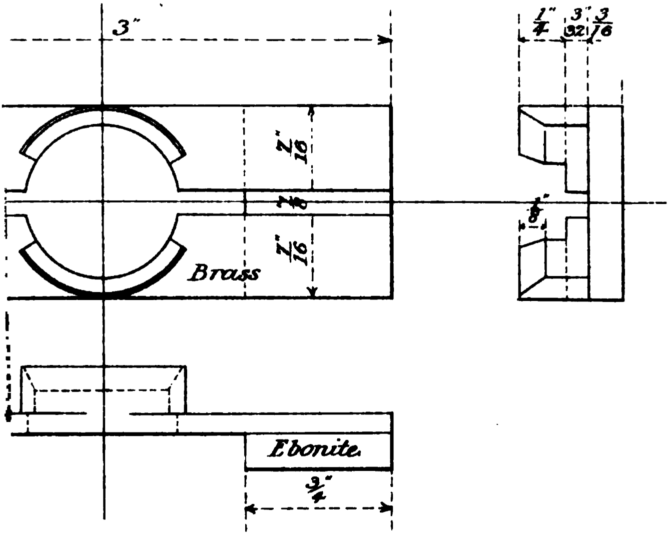
It was observed that the size of the graphite plates mechanically suspended in the metals were largest in the most phosphoretic metal, and less so in those with lower percentages.

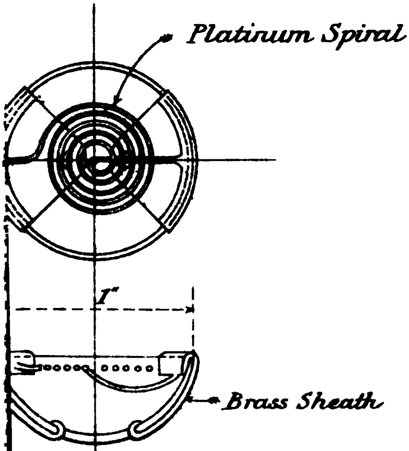
No. 1 metal had the greyest fracture; the others were less grey, the greyness decreasing with the increase of phosphorus.

The analyses prove that this decrease was not due to the presence of combined carbon, for the least proportion of that substance is found in the most phosphoretic sample; it therefore must be due to the decreasing proportion of graphite.

It is unfortunate that the silicon was not equal in each case for the sake of strict comparison; but for all that, the results are instructive, considering that the variable element silicon was not in greater proportion in the more phosphoretic metals Nos. 4 and 5 than is commonly present in grey furnace irons; and that even although not excessive, combined carbon was absent, and all the carbon capable of being absorbed was in the state of graphite.

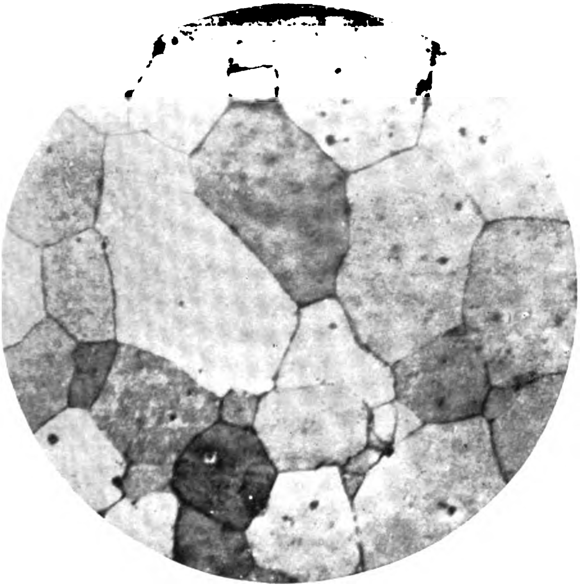
PLATE I.



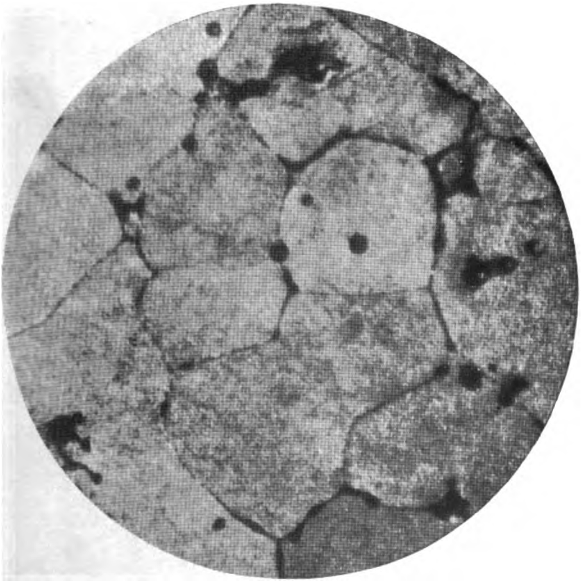


ional Elevation.

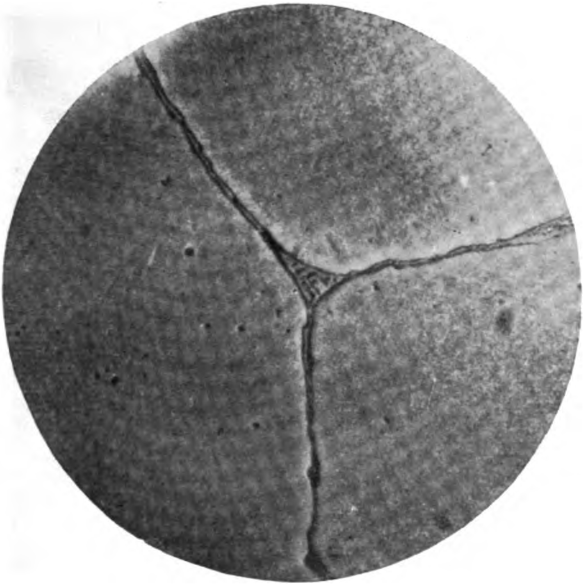
Ballantyne, Hanson & C° Edinburgh & Lon



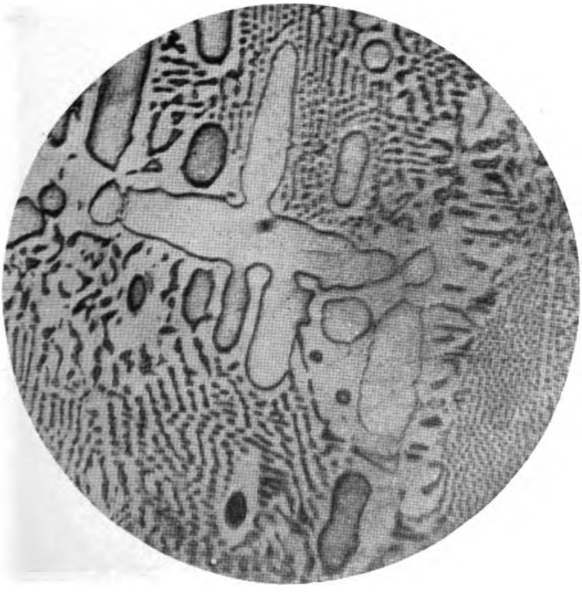
No. 1. Type of all the metals in Class I.—Polygonal crystalline grains. Solid solutions of Fe_3P in iron. The grains, under like conditions of heating and cooling, increase in size with the increase of phosphorus. V × 50.



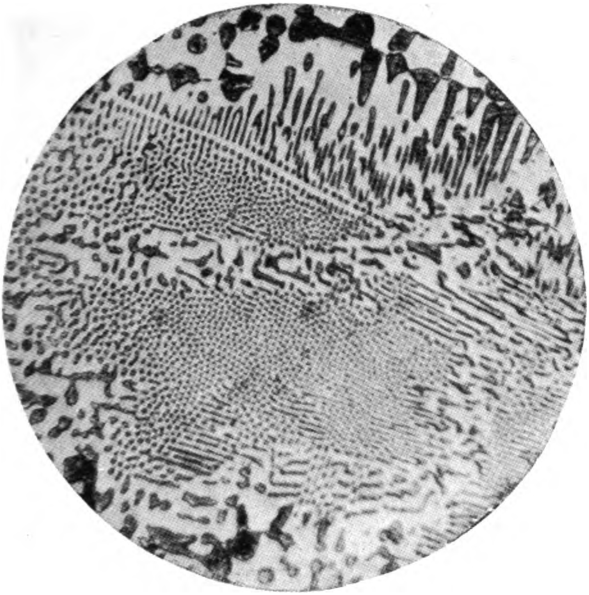
No. 1a. Metal ingot containing 0.8 per cent. phosphorus and no carbon, and some oxide of iron in globules and in incomplete cells surrounding the grains. Strongly etched with nitric acid (20 per cent.). The dark bands in the illustration are spaces dissolved away by the acid. V × 50.



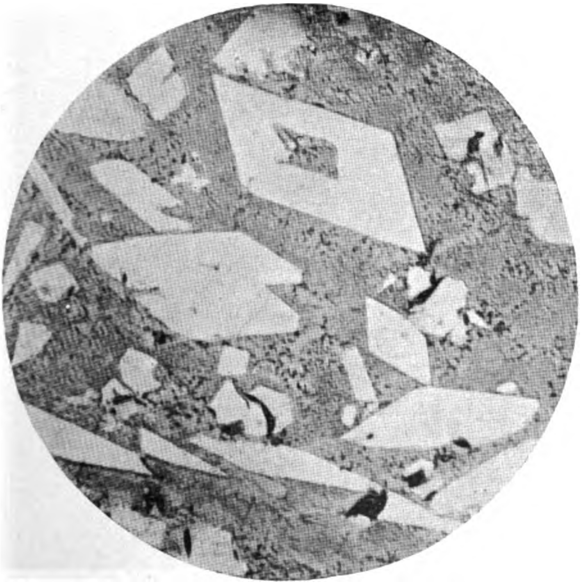
No. 2. Metal ingot with 1·8 per cent. phosphorus, showing portions of three contiguous grains surrounded by a cellular envelope of Fe_3P with a little of the eutectic at the part where the three grains meet. V × 350.



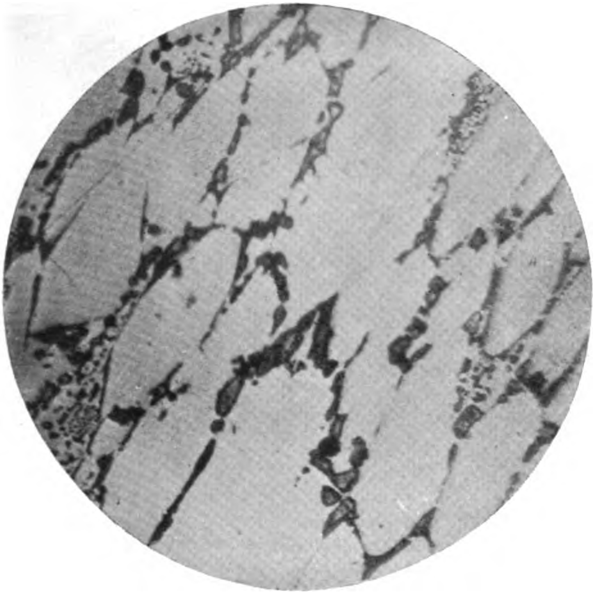
No. 3. Metal ingot containing about 8 per cent. phosphorus. The broad light parts are crystallites of the metal containing about 1·7 per cent. phosphorus. The white mottled ground mass is the eutectic containing 10·2 per cent. phosphorus. V × 250.



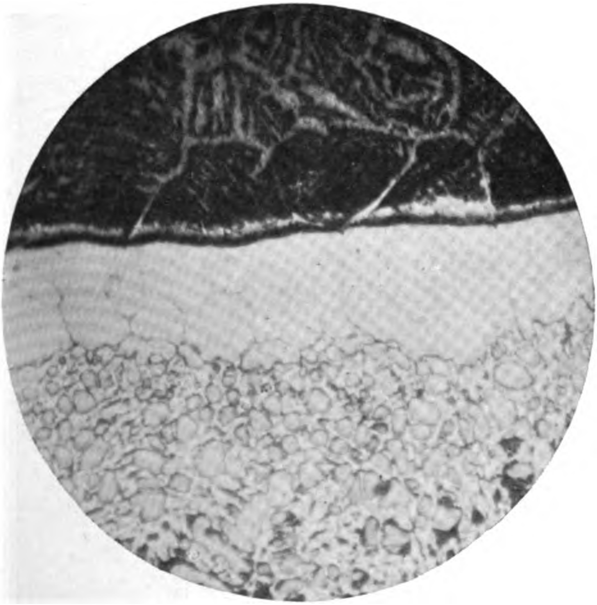
No. 4. Ingot containing 10.2 per cent. phosphorus and 89.8 per cent. iron. It is the eutectic of phosphorus and iron. It has only one critical point at about 980° C. Etched with nitric acid. V × 350.



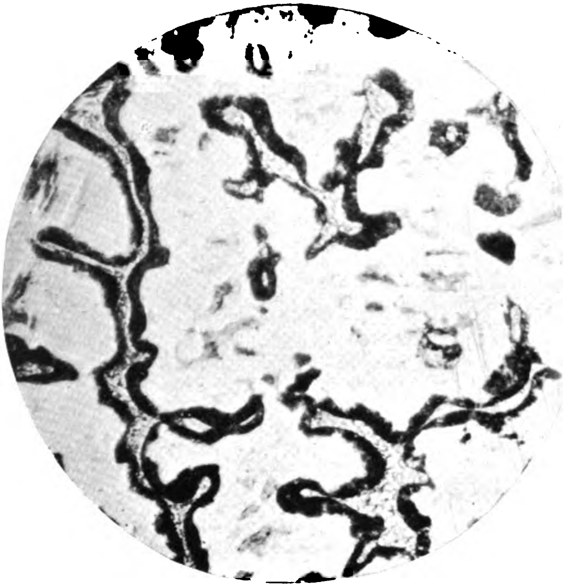
No. 5. Ingot containing 11.07 per cent. phosphorus and 88.9 per cent. iron, showing sections of rhombic or oblique idiomorphic crystals of Fe_3P embedded in a ground mass of the eutectic. V × 60.



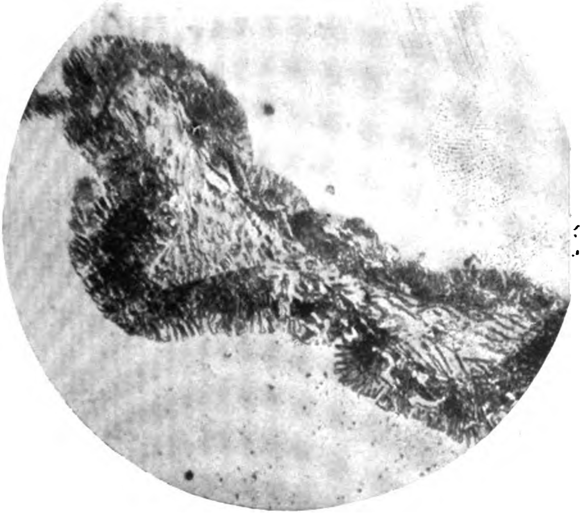
No. 6. Ingot containing 15.15 per cent phosphorus, consisting of crystalline grains or allotriomorphic crystals of Fe_3P surrounded by the eutectic. V × 100.



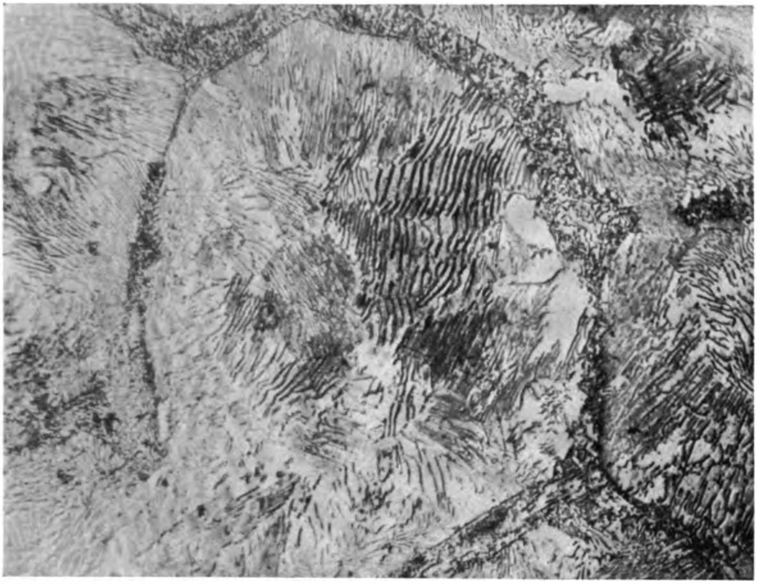
No. 7. A section of a bar of soft steel which was allowed to partly dissolve and then to cool in molten phosphide eutectic, showing the steel at the top, then the white band of solidified solution of phosphide in iron through which rivers of the Fe_3P pass, and below this the structure of the metals of Class II. V × 100.



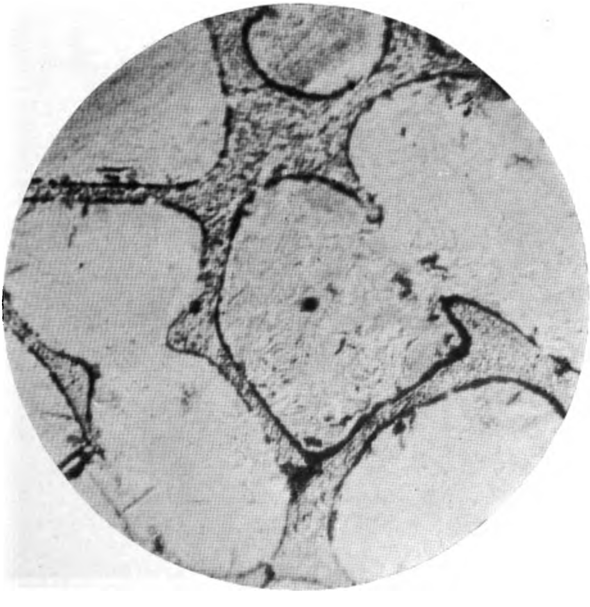
No. 8. Ingot containing 1.74 per cent. phosphorus and 0.18 per cent. carbon. The mottled portions surrounded by dark borders are the eutectic of phosphide of iron. The borders are pearlite. The white ground mass is the solid solution of phosphide of iron in iron. V × 60.



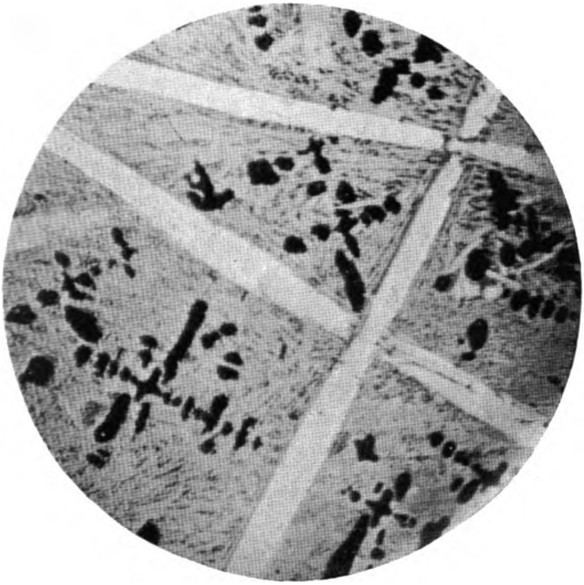
No. 9. A portion of the last more highly magnified, showing the fringed character of the pearlite and broken-up structure of the eutectic. V × 350.



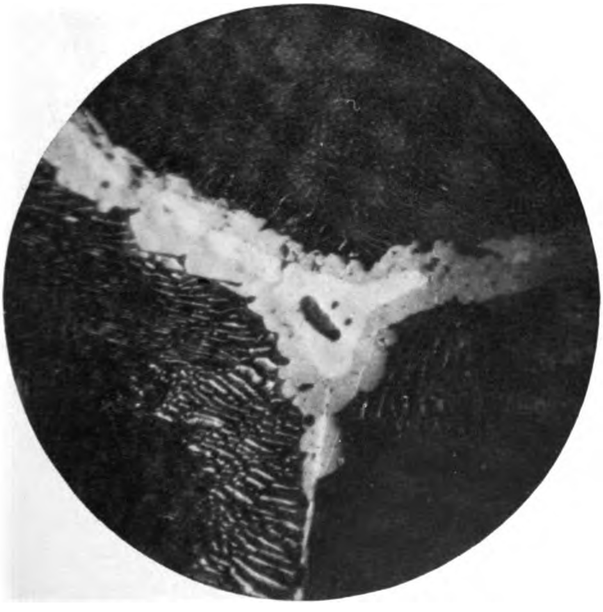
No. 10. Ingot containing 1.7 per cent. phosphorus and 0.71 per cent. carbon, showing a large grain surrounded by the eutectic. The body of the grain consists partly of solid solution of phosphide of iron in iron (white), and the greater part of pearlite (banded). V × 250.



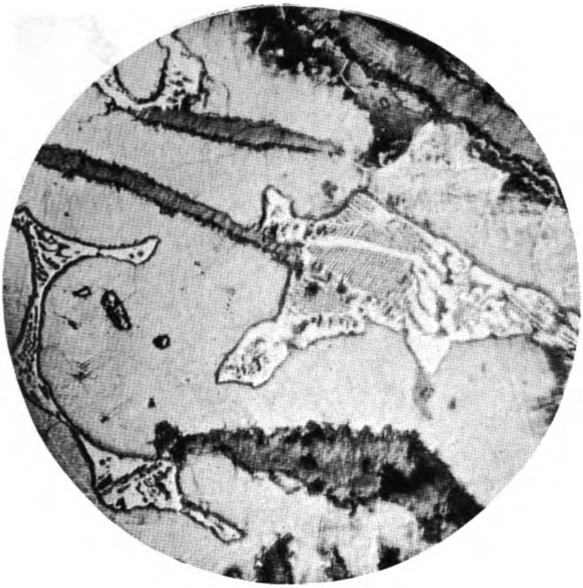
No. 11. Ingot containing 1.7 per cent. phosphorus and 1.4 per cent. carbon, polished and heated till the eutectic was tinted pale yellow. The dark band is carbide of iron. The pearlite grains were blue with brown laminæ of cementine. V × 350.



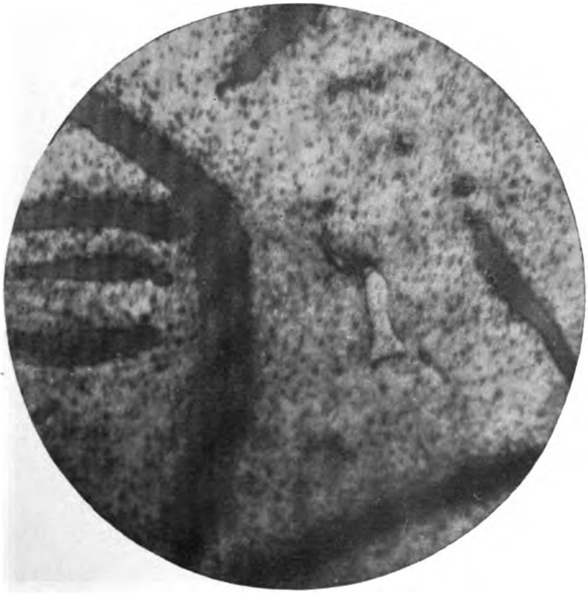
No. 12. Metal containing 6 per cent. phosphorus and 1.6 per cent. carbon, showing white sections of cementine plates, the ground mass of the eutectic, and the black pearlite areas. V × 100.



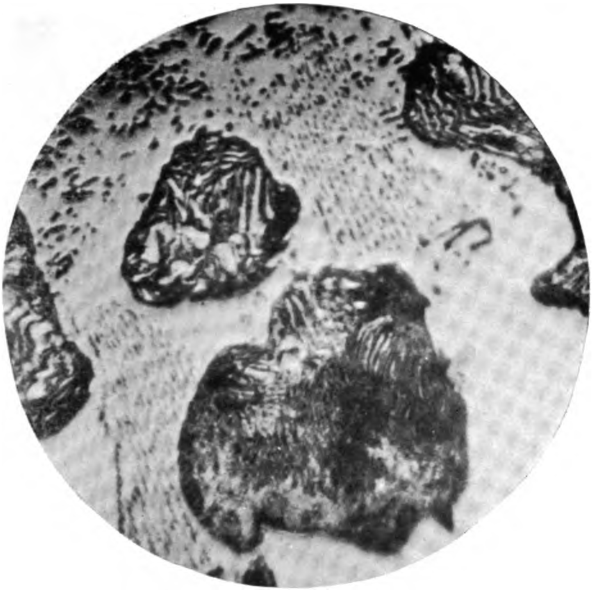
No. 13. Mass of slowly cooled steel from the bottom of an open-hearth furnace containing 1.2 per cent. carbon and 1.3 per cent. phosphorus. The section was first etched with iodine to darken the pearlite. It was then heated till the borders of the cell walls assumed a pale yellow tint. The interior portion of the cell walls are phosphide of iron (white), the exterior parts cementite (half-tone), the dark parts pearlite. V × 250.



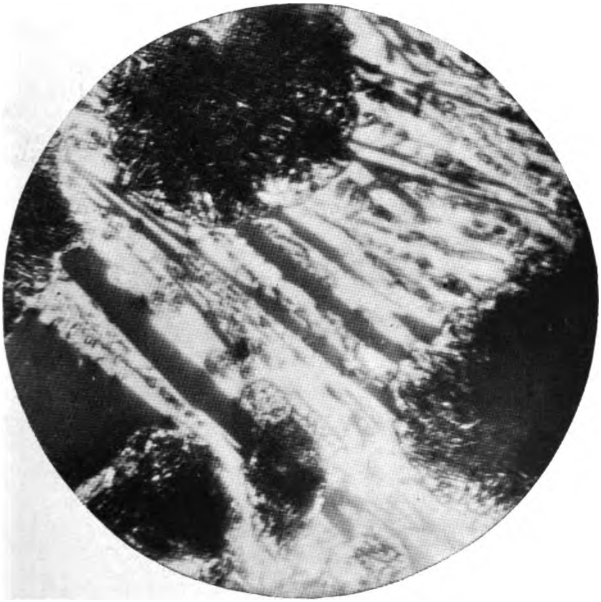
No. 14. No. 3 Cargo Fleet Cleveland pig iron, showing dark sections of the graphite plates, the broken-up structure of the phosphide eutectic, and the ground mass of iron with silicon and manganese. V × 250.



No. 15. East Coast hæmatite, showing small phosphide area in centre, the section of the graphite plates surrounding it. V × 250.

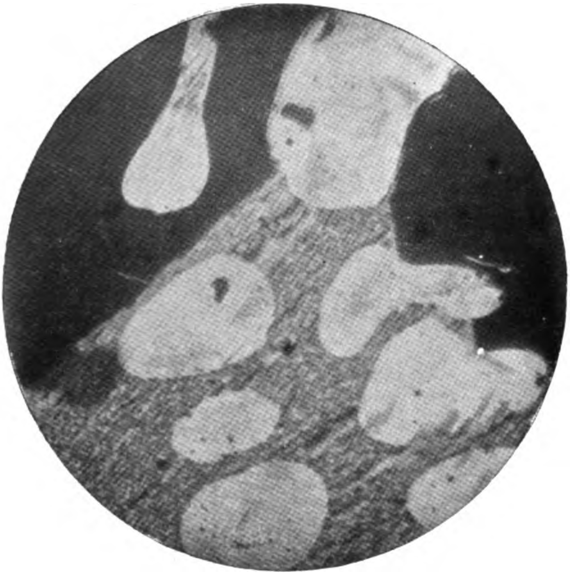


No. 16. White Clarence pig iron etched with iodine. The white parts represent the carbide and phosphide areas. The dark areas represent the pearlite. V × 250.

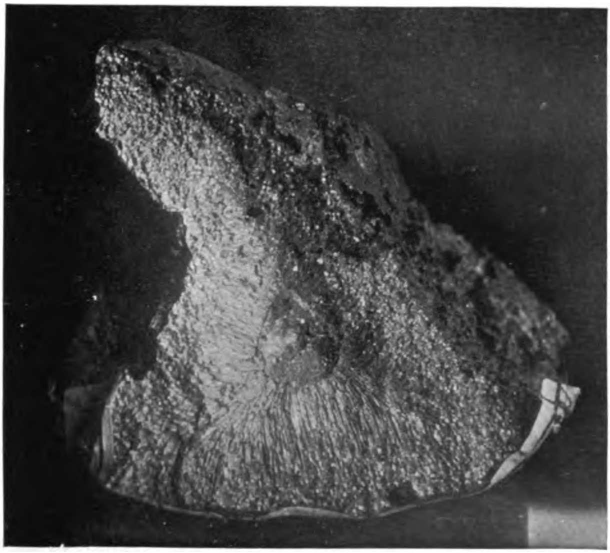


No. 17. White Clarence pig iron, etched to darken the pearlite, then heated till the cementite became yellow, the phosphide of iron remaining white. The dark parts with irregular borders on the top and on the right are pearlite. The large flat dark area on the left is massive cementite. The black and white areas in the middle are the compound phosphide eutectic.

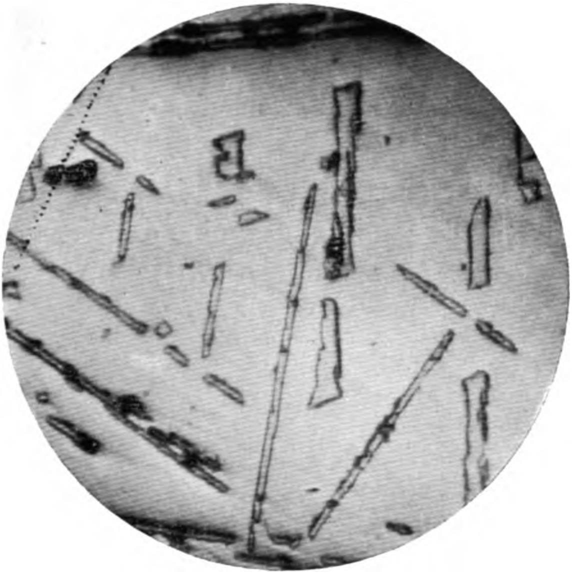
PLATE XI



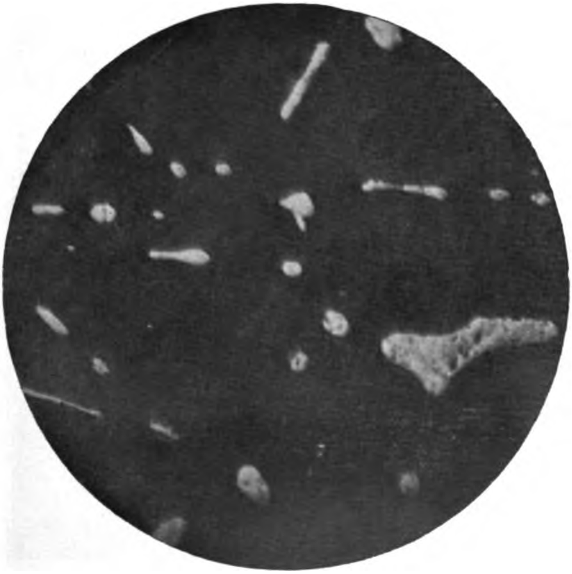
No. 18. Basic pig iron containing about 3 per cent. phosphorus. The structure was revealed by heat tinting. The dark areas are massive cementite. The globulites, pearlite, and the broken-up structure is the phosphorus eutectic. V × 350.



No. 19. Natural size of the fractured surface of a piece of metal containing originally about 1.96 per cent. phosphorus after carburising by cementation, showing crystalline columns radiating from the central kernel of unaltered metal, formed when the iron changed from the beta to the gamma state.

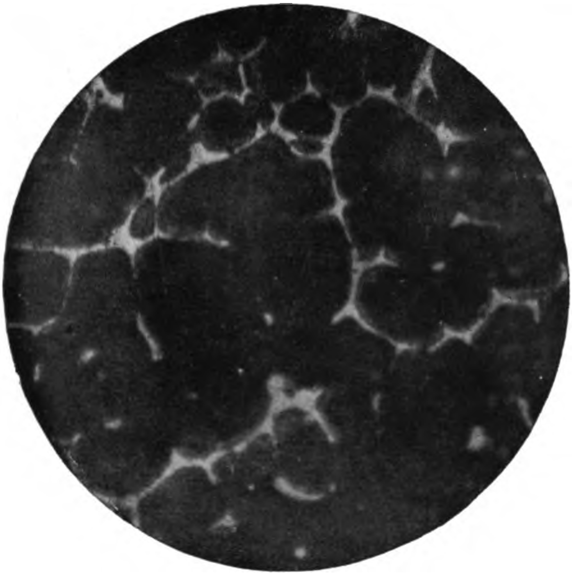


No. 20. Metal containing about 1.95 per cent. phosphorus and 0.18 per cent. carbon after repeated annealing in a malleable castings furnace, showing prismatic crystals of free phosphide of iron. Phosphorus in solid solution = 1.06 per cent. P.; in free phosphide = 0.88 per cent. P. V X 60. The original metal before annealing is illustrated by Photo No. 8.



No. 21. The same as the last, after heating to about 1100° C. Phosphorus in solid solution = 1.01 per cent. P.; in free phosphide = 0.95 per cent. P. V X 60.

PLATE XIII.



No. 22. The same as the last, after melting in a magnesia crucible. This contained 1.74 per cent. P. in solid solution, and 0.20 per cent. P. in the free phosphide. V X 60.

SUMMARY OF PART II.

1st. That on melting saturated solid solutions of phosphide of iron in iron with carbon, the latter causes a separation of the phosphide near to the point of solidification, which appears in the solid metal as a eutectic in irregular-shaped areas, if the carbon present is small and in envelopes, increasing in thickness with the amount of carbon present, but is incapable of throwing the whole of the phosphide out of solution even when 3·5 per cent. carbon is present. A residuum always remains in solid solution. This residuum is smallest, however, when the carbon is at a maximum.

2nd. The residuum appears to be retained in the pearlite, which, when much phosphorus is present, amounts to about 0·60 per cent. when the mass has been very slowly cooled, and about 0·75 per cent. when cooled more rapidly.

3rd. That a portion of the phosphide of iron in steels containing under 0·10 per cent. of phosphorus is thrown out of solution by carbon when it exceeds 0·9 per cent., and the phosphide so separated is liable to form a brittle cell structure enveloping the grains, yielding a more or less fragile mass. In such cases, however, the larger part of the phosphide remains in solid solution.

4th. That when phosphoretic iron is carburised by the cementation process the carbon at once causes a separation of phosphide from the solid iron if it is saturated with phosphide and continues to cause it to separate until the residue contains 0·6 per cent. phosphorus and 1·3 per cent. carbon. If the iron contains about 0·6 per cent. phosphorus to commence with, no phosphide is thrown out of solution until the carbon is increased above 1·2 per cent., a very different result than is obtained by melting and solidifying material of the same composition.

5th. That if highly phosphoretic steel containing much carbon is heated to above the melting-point of the phosphide eutectic in contact with some absorbent material, the eutectic simply liquates out of the mass and is retained in the surrounding substance; practically only that part of it in solid solution remaining behind.

6th. That when the phosphide eutectic is expelled from the iron by the absorption of carbon in the cementation furnace, a large part of it liquates out of the mass and falls in the liquid state into the surrounding charcoal.

7th. That when saturated solid solutions of phosphide in iron are heated or cooled, they show no thermal critical point at Ar3, and the structure is not broken up even when the temperature exceeds 1000° C.; therefore there can be no allotropic change from the beta to the gamma modification by heating to 1000° C. When, however, carbon passes into the mass, a large proportion of the phosphide is expelled, and the carbon absorbed converts, at the temperature of the cementation furnace, a dominating proportion of the beta iron into gamma iron, and coincidentally the structure is entirely reorganised and recrystallisation is effected. The recrystallisation can only proceed coincidentally with the penetration of the carbon from the exterior towards the centre.

Under favourable conditions the slowly developing crystalline grains develop longitudinally into columns, which radiate to the middle of the bar.

A similar condition of crystalline development follows the change of allotropic state, but in the reverse direction, when carburetted steel is decarburised in ore or limestone at about 750°. At that temperature in presence of diffused carbide the carbon is in the gamma state, but as the carbon is removed beta iron is formed and crystallisation of the iron proceeds from the exterior to the centre of the mass, leaving a most perfect columnar structure.

8th. The proportion of phosphine, PH_3, gas given off on dissolving phosphoretic irons free from carbon is approximately inversely in proportion to the amount of phosphorus.

When 1·7 per cent. is present, only about 4 per cent. of it escapes as gas, whereas when there is only from 0·03 to 0·10 per cent., nearly 70 per cent. of it passes off as PH_3.

9th. When carbon is introduced into irons containing from 0·03 to 0·10 per cent. phosphorus, the proportion of phosphine liberated on solution of the metal steadily decreases with each increment of carbon, until, when the latter reaches about 1·2 per cent., only 15 per cent. of the whole escapes as PH_3. This behaviour leads to the conclusion that there are two solutions in steel above its solidifying point, a solution of carbide and a solution of phosphide. That the carbide solution is the dominant one, and that the solution of phosphide is concentrated more and more into that portion of the iron not dominated by the carbon. In this way is explained the behaviour of acids. The more the solution of phosphide becomes concentrated by the carbon, the less proportion of it is capable of yielding PH_3 when it is treated with acid.

10th. The amount of carbon capable of being absorbed in the blast-furnace and crucible by metal containing phosphorus depends upon the proportion of phosphide of iron present. Pure iron free from phosphorus will combine with nearly 5 per cent.

When the compound consists entirely of Fe_3P, no carbon will enter, and the amount capable of being absorbed in mixtures of iron and phosphides approximates inversely to the percentage of Fe_3P which may be present.

11th. Phosphorus does not appear to cause the separation of graphite from metals high in carbon or conduce to the retention of that element in the combined state. Its action appears to be inert in that respect.

12th. When iron containing 1·7 per cent. phosphorus and no microscopically visible free phosphide is dissolved in either sulphuric or hydrochloric acid, a dense black residue is left behind, insoluble, non-magnetic, and of very complex constitution. It is not a simple definite compound of iron and phosphorus, but most probably a decomposition product of phosphide of iron. A similar substance is slowly formed when pure Fe_3P is acted upon by the same acids.

PART III.

CONSTITUTION AND MICROSTRUCTURE OF PIG METALS CONTAINING IRON, CARBON, AND PHOSPHORUS.

It was (1) Sir Frederick Abel who first discovered that on breaking phosphoretted pig irons just after solidification sometimes a little fluid metal ran out from the central portion, which contained considerably more phosphorus than the average of the pig iron from which it liquated. Since that time many observers have confirmed this result.

In 1870 I subjected to hydraulic pressure in a properly prepared mould Cleveland pig iron after practically the whole of it had solidified. The git or runner was left open when the pressure was applied, with the result that a small quantity of metal was squeezed out. The original metal and fusible portion had the following analysis, viz.:—

	Original Metal. No. 4 Brand.	Portion Squeezed Out.
	Per Cent.	Per Cent.
Carbon	3·00	1·75
Manganese	0·35	0·29
Silicon	1·63	0·79
Sulphur	0·12	0·06
Phosphorus	1·53	6·84

(15) Mr. Osmond has described certain experiments of his in which he proved the existence of a critical point in the solidification of phosphoretic pig iron at about 900° C. The analysis and critical points were as follows:—

Phosphoretic Metal.

	Per Cent.
Graphite carbon	1·50
Combined carbon	1·20
Manganese	0·74
Silicon	1·89
Sulphur	0·03
Phosphorus	1·98

Critical Points.

	III.	II.	I.	Ar 1, 2, 3.
Cooling	1065	1025	895	698
Heating	1050	1040	910	800

Comparative analysis and critical points of hæmatite pig iron containing practically no phosphorus are given below. These are also by Mr. Osmond, viz.:—

Hæmatite Metal.

	Per Cent.
Graphite carbon	2·25
Combined carbon	1·04
Manganese	0·11
Silicon	2·45
Sulphur	0·06
Phosphorus	0·054

Critical Points.

	Solidifying Point.	II.	I.	Ar 1, 2, 3.
Cooling	1240?	1140	1090	708
Heating	...	1155	1100	780

The characteristic difference between the two irons is, that in hæmatite pig iron there is an absence of a critical point at about 900° C. Mr. Osmond proved that this was peculiar to phosphoretic iron, and showed by experiments made by Mr. Lencauchez (18) that a compound high in phosphorus existed in pig iron which was more fusible than the greater mass of the iron. The results quoted are as follows:—

100 kilos. of Longwy iron were heated to 950° C. in a reducing gas for 100 hours. When cold, although the pieces had preserved their form, on the surface was observed a multitude of little spherical metallic particles like small lead shot. Some of these had joined together and run off the surface and had fallen on to the bottom of the retort, where they solidified. The following analyses give their composition, viz.:—

	Shot.		Liquate.	
	1.	2.	1.	2.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Combined carbon	1·24	...	0·90	...
Graphite	0·75	trace	1·50	1·50
Silicon	0·82	0·63	1·41	2·17
Phosphorus	5·45	6·00	4·48	4·40

Previous to heating, the metal contained—

	Per Cent.
Carbon	3·50
Silicon	2·60
Phosphorus	1·90

The analysis of the shot, it will be observed, closely resembles the analysis of the metal which in my own experiments I squeezed out of Cleveland pig iron by hydraulic pressure.

The phenomena observed by Mr. Lencauchez is peculiar to metals containing small quantities of a fusible eutectic, or a constituent which is more fusible than the greater mass, for I have found that it is only necessary to heat such alloys or compounds a little above the melting-point of the eutectic for small globular exudations to pass out of the metal, forming little shot-like bodies all over the surface. It is not difficult to understand how this occurs, for as soon as the temperature is raised slightly above that of the liquefied eutectic it expands, and a portion of it comes out of the metal in which it was imprisoned. There is also always a tendency in heterogeneous mixtures of metals for that part which is in greater mass to throw off the others in contact with it; hence small quantities of the eutectics, where it is physically possible, are thrown into large segregated areas or entirely outside the mass.

I have most carefully repeated Mr. Osmond's experiments, and find that in Cleveland iron, when it is slowly cooled from the molten state, there is a critical point at about 900° C., thus confirming his observation. The pure eutectic of phosphorus and iron solidifies at about 980° C., so it is clear the eutectic solidifying at 900° C. must have a different composition.

On melting together some of the phosphide of iron eutectic with carbide of iron, the eutectic formed solidified at 910° C. A similar result followed on cooling a mixture of silicious pig iron with the pure eutectic.

Leopold Schneider succeeded in isolating the free phosphide of iron from phosphoretic pig irons by dissolving them in cupric chloride, and found it to correspond to the composition expressed by the chemical formula Fe_3P.

In order to isolate the eutectic from grey Cleveland iron containing 1·56 per cent. phosphorus, some lumps of it were dissolved in dilute acid. The residue, containing graphite and decomposition products of the phosphide in solid solution, and the eutectic and carbide of iron, had the two latter bodies removed from it by a magnet. The material so attracted was treated with cupric chloride to decompose the free carbide of iron, and the phosphide eutectic remaining was attracted from the residue magnetically. On testing a very small portion of what was obtained, it yielded about 0·70 per cent. silicon. A second portion ground to powder in an agate mortar was treated with nitric acid of specific gravity 1·20 to remove the soluble iron and silicide. The residue contained 15·1 per cent. phosphorus instead of 15·56 per cent. It may be considered to be nearly pure Fe_3P.

It would appear from this result that silicide of iron dissolved in iron is a constituent of the phosphide eutectic of grey silicious pig irons.

The last fluid portion squeezed out of Cleveland pig iron referred to on page 116, shows that from a forge iron containing 1·63 per cent. of silicon, what was expressed contained 0·79 per cent. silicon, and 1·75 per cent. carbon, and nearly 7 per cent. phosphorus.

The exact composition of eutectics in pig iron evidently requires more careful study. It is a somewhat difficult subject to master, but it is hoped that the foregoing remarks will lead others to endeavour to take up this interesting branch of research.

In view of these researches, it was naturally to be expected that the microscope would be able to detect the fusible phosphide eutectics in pig metals.

Practical observation of Mr. Osmond and myself, working independently, fully confirmed such a conclusion, for it has been proved beyond all doubt, that in grey pig iron containing only 0·03 per cent. phosphorus the phosphide eutectic can be detected by the microscope, and with quantities greater than that it is in great evidence.

It is in grey irons free from massive cementite where the eutectic can be most easily detected, for then a simple acid etching process is sufficient to reveal its presence.

In following what occurs when grey phosphoretic pig iron solidifies, it would appear that the thick plates and semi-spherical shells of graphite first fall out of combination with the iron, leaving the remaining portion of the metal still in a plastic state; but this, as heat passes away, in time begins to solidify, commencing at the solid borders of the graphite.

This metal consists of all the iron, manganese, silicon, and phosphorus; it does not all solidify at the same time.

The crystalline combination of the greater part of the iron and manganese and all the silicon forms one part; the phosphorus and some of the iron and manganese the other part.

As the first part crystallises in advance, the remainder, consisting of the fusible eutectic, is driven before the metal, advancing in its growth on all sides of it; and finally, when they nearly approach each other, the eutectic (incapable of being forced further in any direction) is imprisoned in irregular-shaped cavities, where it remains fluid till the temperature falls to its freezing-point, when it solidifies, breaking up into its two constituents.

It follows, therefore, that the irregular-shaped solid masses of the eutectic must be found between and at a distance from the graphite plates, and this is actually where the greater number of them are located.

The photographs Nos. 14 and 15 illustrate the foregoing remarks. The first represents the structure of Cargo Fleet No. 3 iron, the second East Coast No. 1 hæmatite. They had the following composition:—

	Phosphoretic.	Non-Phosphoretic.
	Per Cent.	Per Cent.
Combined carbon	0·12	0·25
Graphite	3·59	3·86
Manganese	0·69	0·76
Silicon	2·76	2·83
Sulphur	0·05	0·04
Phosphorus *	1·49	0·04
Phosphorus in solid solution	0·29	0·03

* Equal to phosphide of iron, 9·50 per cent., 0·25 per cent.

The irregular white areas in the centre of the photographs are the phosphide eutectic.

When hæmatite metal is strongly etched, so as to darken the ground-mass, and is examined with vertical light, the specks of brilliant phosphide stand out in bold relief, and appear like the stars on a clear night, the number and size depending on the quantity of phosphorus present and the rate of cooling. When rapidly cooled, they are greater in number but are more widely distributed, whereas in the same slowly cooled material they are less numerous but of greater mass.

It is advisable to etch strongly when looking for phosphorus, and to examine with a high power, when the compound character of the phosphide eutectic will be easily identified.

The structure of chilled and white hæmatites has not yet been thoroughly studied, they are therefore reserved for future research.

In grey irons the amount of the eutectic is proportional approximately to the amount of the phosphorus, so that almost any one with a little practice, and with a standard series of sections, can now, in a few minutes, grind and polish a sample of metal, and approximately estimate the proportion of phosphorus present in it.

In grey pig iron cooled in not too large masses, even in the forge grey quality containing nearly 0·7 per cent. combined carbon, the phosphide eutectic is invariably found in the same position as it is in the very slowly cooled iron.

When the metal is cooled very slowly, and when there is little silicon present and some combined carbon, the latter is found in segregated cementite or carbide of iron; but this, unlike the phosphide, is found surrounding and adhering to the graphite plates, but the phosphide eutectic is quite separate from the carbide and as far as possible from the graphite.

An interesting instance of this has been found in what was alleged to be a natural iron found on the top of a mountain in Norway. On breaking it, it was found to be a coarsely grained dark grey cast iron with a hackley fracture, the analysis of which, as made by one of my pupils, Mr. John Evans, was as follows, viz. :—

	Per Cent.
Iron	95·192
Combined carbon	0·720
Graphite	3·030
Manganese	0·200
Silicon	0·520
Sulphur	0·016
Phosphorus	0·322
Nickel	Nil.
	100·000

The lump of metal was about 5 inches square and 12 inches long. Whether or not it was a natural product is doubtful, but that it had cooled exceedingly slowly in passing from the liquid state was evident, for the carbon which, under less slow cooling, would have existed as pearlite, was massive cementite enveloping the graphite.

White phosphoretic irons are not quite so easy to judge as to the proportion of phosphorus present.

The presence of large masses of carbide of iron makes it impossible to tell which part is phosphide and which carbide if the simple etching method is employed; it is necessary, therefore, to use the "heat-tinting" process.

By heating till the pearlite is blue, as a rule, the cementite will be found red and the phosphide yellow. It is then quite easy to see the proportion of each, and where the eutectic joins the carbide. It has been found better to first etch with iodine to darken the pearlite, and after wiping the specimen with a clean linen rag, to heat till the required tint is obtained. This method leaves the pearlite dark. If the structure is to be photographed, it is advisable to heat until the carbide has assumed a faint yellow tinge, when the phosphide will remain quite white.

By using isochromatic plates, the prints show the phosphides white, the carbide in half-tone, and the pearlite dark.

The photographs Nos. 16 and 17 represent areas of white Clarence pig etched with iodine, and also heat-tinted in the manner described. It will be noticed how the heat-tinting in No. 17 shows up the phosphide, which is represented by the white areas.

SUMMARY OF PART III.

1st. There are fusible eutectics in all pig irons containing phosphorus, and which have solidifying points of about 900° C.

2nd. The free phosphide of iron can be left insoluble from such irons by dissolving them in cupric chloride (Schneider's method), or by nitric acid of specific gravity 1·20 in the cold. By attracting the magnetic portions of phosphide from the residue with a magnet, and further purifying what is attracted, almost pure Fe_3P is obtained.

3rd. With the aid of the microscope it is possible to detect the phosphide eutectic in pig irons, even when the amount is as low as 0·03 per cent.

4th. In white irons it is necessary to use the heat-tinting process to enable the cementite to be distinguished from the phosphide.

5th. The eutectics from such irons have a very complex constitution, containing phosphide of iron, carbide of iron in plates, pearlite, and silicide of iron. They deserve more careful study.

6th. The reason why phosphoretic pig irons are not more brittle than they are is because the eutectic separates into isolated segregations, and does not form continuous cells round the crystalline grains. When the phosphorus does not exceed 1·7 per cent. the metal is comparatively strong, but an addition of 0·3 per cent. reduces the strength materially, the reason of which is that the eutectic brittle areas in metal with 2 per cent. P approach each other closely, leaving less of the strong ground mass intervening.

PART IV.

ON THE DIFFUSION OF PHOSPHIDE OF IRON IN IRON.

(8) Professor Arnold and Mr. MacWilliam have shown that phosphide of iron will diffuse from iron containing 1·36 per cent. phosphorus into pure iron, when they are placed in close contact and are heated in vacuum to 1000° for ten hours.

The relative speed of diffusion of carbon and phosphorus was found to approximate to the ratio of 5 to 1.

That phosphide of iron does diffuse in iron has been fully confirmed by the observations made in my laboratory. One notable instance of diffusion was furnished in a remarkable sample of iron found in the hearth of one of the Ferryhill blast-furnaces after it had been blown out.

As a rule, the "bears" from furnaces are highly carburetted and are associated with much graphite, but this sample was quite an exception to the rule, for it was free from carbon, and, moreover, contained not a trace of silicon and manganese. The structure resembled that of the columnar iron already referred to, with this difference, that the columns were much larger and were greatly curved. The microscope showed that they were enveloped with thin layers of phosphide of iron, and in their centres there existed small globular masses of the same substance, together with globules of sulphide of iron.

The analyses of Ferryhill pig iron and of this curious formation are as follows:—

	Ferryhill Pig Iron.		Sample from Furnace Hearth.
	Grey.	White.	
	Per Cent.	Per Cent.	Per Cent.
Iron	91·10	92·90	91·06
Graphite	3·36	...	Nil.
Combined carbon	0·16	3·20	Nil.
Manganese	0·66	0·25	Nil.
Silicon	2·53	1·10	...
Sulphur	0·06	0·30	0·32
Phosphorus	2·01	2·10	1·98
Oxygen, &c.	0·12	0·15	0·64
	100·00	100·00	100·00

By crushing the sample to fine powder and removing the fine particles by sieving, the greater part of the brittle and easily crushed and free phosphides were removed. On treating the fine powder so removed with sulphuric acid, the sulphides were dissolved, together with that part of the iron which passed the sieve. The insoluble residue, consisting of a black powder and bright metallic particles, was separated into two parts by a magnet, the bright particles being attracted, the black powder remaining behind. The metallic powder had the following composition:—

	Per Cent.
Iron	84·00
Phosphorus	15·41
Not determined	0·59
	100·00

It is practically pure phosphide of iron, Fe_3P, proving the correctness of the microscopic observation.

The iron portion which remained on the sieve had the following composition:—

	Per Cent.
Iron	98·20
Sulphur	0·09
Phosphorus	1·47
Oxygen, &c.	0·24
	100·00
Phosphorus as Fe_3P	0·03
Phosphorus in the columnar masses	1·44

It is not certain that the iron which originally entered the hearth was grey or white, but it is immaterial in which state it was. It must have been fluid to get there at all, and if it was fluid at the temperature of the blast-furnace, after solidification it must have been carburetted, and contained not more than 0·5 per cent. of the phosphorus in solid solution, and about 1·5 per cent. as free or separate phosphide of iron. It is difficult to understand how the metal was oxidised, but it appears probable that it was subjected to the action of water vapour, which would oxidise the manganese and silicon, and probably a portion of the carbon, when the metal was still in the fluid state.

The last 1·5 per cent of the carbon, at least, must have been removed when the metal had become solid, for the temperature would not be sufficient to retain it in a fluid state. The greater part of the phosphide must still have existed in the separate state at the stage when 1·5 per cent. carbon was present.

If these conclusions are correct, and I think there can be little doubt that they are, the carbon as it was removed from the solid solution must have been replaced by the phosphide which diffused into the iron from the segregated little masses of free phosphide, producing a final solid solution containing 1·44 per cent. phosphorus, a diffusion equal to about 1 per cent., which had passed into the iron from what must originally have been free phosphide. The time occupied in effecting this result probably was very protracted. Possibly it took years.

It is evident, however, that although the change was very slowly effected, and that there was more than sufficient phosphide present to give a *saturated* solid solution of the phosphide the amount which actually did diffuse into the iron was short of that quantity by about 0·30 per cent.

The peculiar columnar structure of the metal was no doubt produced when the gamma iron, dominated by the carbon, changed to beta iron, when the carbon was replaced by phosphide of iron.

I am conscious, on comparing the results here recorded with those obtained by decarburising phosphorus iron in the malleable castings furnace previously given, that I am at a loss to understand why there is such a wide discrepancy in the proportion of phosphorus left in solid solution in the two cases. I am, however, certain of the facts, and it remains to find a satisfactory explanation. The conditions, which of course must have been widely different, possibly may account for the anomalous results.

Many experiments have been made in my laboratory to ascertain how phosphide of iron penetrates into steel when the former is maintained in the liquid state. One result yielded most interesting results.

Some fluid eutectic in a crucible was maintained in the liquid state at 1000°, near its solidifying point, in contact with a half-inch soft steel bar containing 0·12 per cent. carbon. The bar was placed vertically through the middle of the fluid eutectic. After keeping them in contact for about an hour, the crucible with contents was allowed to cool down. The compound mass was then sectioned for micro-examination. The bar was found partially dissolved in the eutectic, and was reduced in diameter in consequence to about $\frac{1}{4}$-inch. On polishing and heat-tinting, and then etching by iodine, the following interesting observations were made, viz.:—

The bar was surrounded by a bright hard ring, apparently free from carbon, which was traversed by solidified "rivers" of Fe_3P, which appeared as if they had been flowing from the eutectic through the hard ring into or near to the iron core. This ring consisted of a solidified solution of phosphide of iron in iron. The temperature was never nearly high enough to melt this hard envelope. Between this hard bright ring and the bar there was a transition ring or envelope not so hard as the first, but slightly harder than the bar itself. This envelope was very thin; it did not apparently contain any carbon, and most probably was only partially saturated with the phosphide. At certain points the ferrite areas of the bar continued in unbroken tracks right up to and through the thinner ring into the hard ring.

It was observed that in the central portions of these there existed hard spines, consisting probably of the same constituent as one or both of the rings, and occasionally in the centre of a spine there appeared the fine tapering terminus of one of the streams of phosphide, which could be traced right through both of the rings to the eutectic. Although at intervals the ferrite of the bar joined the inner ring, the greater part of the circumference of the latter was in juxtaposition with pearlite, and where the barrier of pearlite faced them no phosphide penetration could be observed. (Photo No. 7.)

It is proved then that, under such conditions, liquid phosphide preferentially, actually flows into the iron along the junctions of the crystalline grains and then diffuses in the solid state into the iron, and apparently diffuses more readily into iron than into steel.

SUMMARY OF PART IV.

1st. The observations of Professor Arnold and Mr. MacWilliam proving that solid phosphide of iron does diffuse when in the solid state into solid iron under certain conditions have been fully confirmed.

2nd. That if time is given, the quantity which will diffuse into iron is very considerable, amounting to what is equivalent to about 1 per cent. of phosphorus.

3rd. It still remains to be proved at what temperature diffusion commences.

On a previous occasion I made the statement that at that time "they were simply in a fog at present, and could not explain the exact nature of the changes which took place when solids or liquids diffused into solids. Theory and discussion would probably direct their attention to certain grooves in which practical experiment should be made to enable them to explain it satisfactorily. They were not in a position as yet to dogmatise." More data and light was required on this obscure subject, before we could understand it thoroughly, and I think the little work I have accomplished more than justified the remark. A little more light has been thrown on a somewhat complicated question, but before correct generalisations can be arrived at more workers at the research are required and more of nature's revelations obtained.

In conclusion, I must acknowledge the assistance and co-operation of Sir William Roberts-Austen, Professor Bauerman, Professor Arnold, Mr. MacWilliam, Mr. F. W. Harbord, Mr. A. Richards, Mr. J. L. Potts and Mr. Duckinfield of Messrs. J. H. Andrew & Co., Ltd. of Sheffield, Mr. A. Cooper, Mr. C. H. Ridsdale, Mr. T. W. Sorby, Mr. E. H. Saniter, Mr. David Evans, Mr. Horard Livens of Messrs. Ruston, Proctor, & Co., and my own assistants.

Without the assistance of these gentlemen I could have done little work.

APPENDIX I.

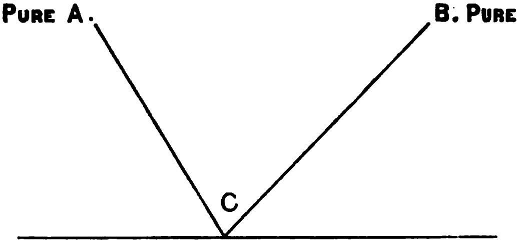
EUTECTICS.

As the words "eutectic" and "eutectic alloy" are now very generally used, it is important it should be clearly understood what is meant by the terms.

It was Guthrie who first applied it to the study of alloys.

Sir William Roberts-Austen has kindly given me his views on eutectics as follows:—

As regards the definition of a eutectic, reference to Guthrie's original paper, *Phil. Mag.*, June 1884, shows that he intended the word "eutectic" to refer to a solidified "mother liquor," that is to a mixture which has a lower freezing-point than any other of the series. The simplest case is a mixture of the two dissolved bodies A and B, the proportion of each that is present depending on their relative solubilities in each other.

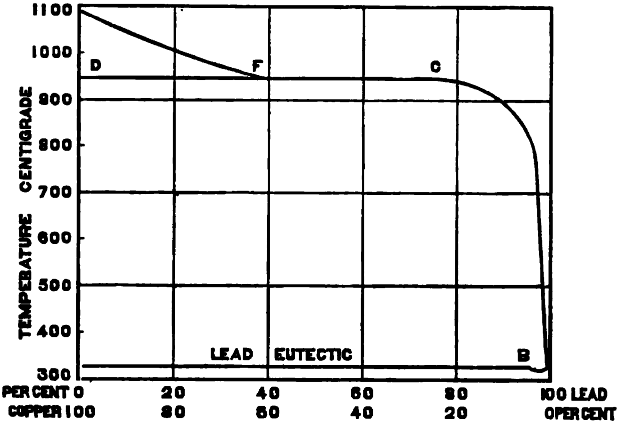


Mechanical mixture of A and B.

It happens, however, that in certain series of alloys the two constituent metals form a true compound which acts like a third body, and this forms a separate eutectic mixture with each of the two constituent metals. Each of these mixtures has a definite composition and solidifies at a definite temperature, whatever may be the composition of the substances which "fall out" from it and the temperature at which they "fall out."

It is convenient to call all such mixtures "eutectic" alloys. A case is presented by the following system:—

The liquid which solidifies at the point C (p. 128) is a true eutectic, because the adjacent alloys, as indicated by the lines CA, CB, are less fusible than it is. The existence of other more fusible alloys in the series would not affect its position as a eutectic alloy, provided the lines CA and CB both slope upwards. If, however, one of these lines does not slope up as in the lead-copper series, (22) "Fourth Report to the Alloys Research Committee of the Institution of Mechanical Engineers," plate 7, at the point F, the alloy which solidifies is not a true eutectic, although it was first so called for want of a better term. In the copper-lead series the line DFC is horizontal, and represents the solidification of one of the two conjugate liquids into which the fluid alloy separates.



On reading the paper of Guthrie referred to by Sir W. Roberts-Austen, it is clear that he recognised that the eutectic proportions of the metal present had not necessarily any relation to their atomic weights, and says, "Of course in many cases, metals can be fused together in simple multiples of their atomic weights, but in most such cases, one of the metals will separate out first and so destroy the ratio." . . . "When we are dealing with metals which, like antimony or arsenic, are themselves halogenous, or with such strongly chemico-positive metals as sodium on the other, we may and do get alloys of atomic composition or metallo-metallic salts. But the temperature of fusion of these are never, so far as I am aware, lower than that of either (both) of the constituents: they are not eutectic."

This last sentence makes it clear that one property of a eutectic, according to Guthrie, is that its melting-point must be lower than that of the mean of the separate constituents. All of the instances quoted in his paper illustrate this second principle.

Recognising that certain metals may combine to form metallo-metallic salts, Guthrie, by inductive reasoning, concluded that in an alloy such salts might be formed, and that they would take the part of a free metal and form eutectic alloys with one or other of the constituents. He says, "The very bodies resulting from the chemical union of the two metals will possibly and probably furnish starting-points of new series of eutectic alloys, consisting of a single metal on the one hand and the chemical alloy on the other."

Professor Guthrie prepared any given eutectic by melting the metals and then allowing that metal which happened to be in excess to crystallise or fall out of solution, and when the greater part had become solid, the residual alloy which still remained fluid as a kind of "mother liquor" was poured off and allowed to set. This crude eutectic was remelted and allowed to partially solidify, and the mother liquor again poured off. The same treatment was repeatedly applied until the mother liquor invariably yielded the same constant composition. This alloy when solid, but for the contradiction in terms, might have been called a solidified mother liquor. Guthrie applied the term eutectic.

A eutectic, then, must have the following properties and components:—

1st. A solidifying and melting point lower than that of the mean of the constituents.

2nd. A single melting and solidifying point.

3rd. It may consist of two or more metals which do not unite chemically, or of a metal and a definite chemical compound, and possibly of two or more definite chemical compounds.

Recent research has shown that it may be constituted as follows:—

4th. It may consist of a mixture of a solid solution of one metal in another and a free metal.

5th. It may contain a solid solution of a definite chemical metallo-metallic salt, and that same metallo-metallic salt in the free state.

6th. It may possibly consist of two solid solutions.

7th. Is an exception to the general rule, and relates to the eutectic pearlite which is formed in solid steel when it cools slowly from 700° C. to below 400° C. It is a solid solution at 700° C., but splits up into two constituents on cooling.

8th. A eutectic may contain two eutectics, one formed at its solidifying point, the other of pearlite formed on cooling below 700° C. The more fusible part of white pig iron, free from phosphorus and high in carbon, is an instance of this.

Preparation of Eutectics.

The method of Guthrie is undoubtedly the best for making the eutectic mixtures, but it necessitates using large quantities of the metals. The second in value is that in which the metal is poured into a cylindrical cast iron mould lined with loam, and after solidification is nearly complete, it is compressed by hydraulic pressure, and the eutectic squeezed out of a suitable opening.

Sir W. Roberts-Austen has employed a similar plan to this. It is described in his Fourth Report on Alloys to the Institution of Mechanical Engineers, 1897.

"The alloy under examination is placed in a steel cylinder, which is fitted with two loose steel plungers, each about ½-inch diameter. The whole is placed between the jaws of a hydraulic press, and a pressure of about half a ton per square inch is maintained on the ends of the plungers. The cylinder is then slowly heated, the temperature at any moment being measured by a thermo-couple, which is placed in a hole drilled in the cylinder. At a certain definite temperature part of the alloy will liquefy, and can be squeezed out between the plungers and the wall of the cylinder. The temperature is noted at which the alloy is sufficiently liquid to be extruded. The heat is then raised, and a further portion of the alloy can sometimes be separated. Finally, a comparatively infusible residue is left. These several portions are then analysed. In some cases it is found to be desirable to subject the extruded portions to a second treatment in the compressing cylinder."

It was the hydraulic method I used in expressing the liquid eutectic from Cleveland iron, and it is the best in cases where a small quantity of the eutectic is in presence of a large mass of metal.

A third method useful in such cases where the fusing-point of the alloy is under 500° C., and where only small quantities are available, has been employed with great advantage in my laboratory in preparing the eutectics of the fusible metals.

The melted alloy is poured upon the surface of a sheet of flexible asbestos paper. When the mass has solidified to the consistency of a thick paste, a second sheet of asbestos is placed on the top of the metal, and a wooden ruler is rolled over the plastic mass from the front in a forward direction. The eutectic is in this way squeezed out and runs as a fluid drop in front of the ruler leaving the solid metals behind. The crude eutectic so obtained is remelted and is again subjected to the same treatment. It is possible in this way to obtain the eutectic from 10 grammes of alloy.

The last method is that which I have used most extensively in the preparation of the eutectics containing two metals. It may be called the microscopic method. It is based upon the characteristic micro appearance of nearly all the eutectics, and on the statement of Guthrie, now generally recognised, that if one of the constituent metals is present in excess it will first solidify, leaving the residual eutectic to solidify at a lower temperature. The metal which falls out of the mother liquor is clearly seen in the micro section when it is properly polished and etched. It generally takes some clearly marked crystalline form.

Having prepared several mixtures synthetically by melting the metals in several proportions, and allowing them to solidify slowly, pieces of each are cut, polished, etched, and examined. As a rule, it does not take more than ten minutes to prepare a specimen. A glance through the microscope reveals at once which specimen contains the greatest proportion of the eutectic and which metal is in excess. Several further alloys are then made approximating to this, but with diminishing proportions of the metal known to be in excess. The resulting mixtures are examined, and probably one of them will be found to consist of pure eutectic, free from crystals or crystallites of either the constituent metals. A chemical analysis is then made to check the figures synthetically obtained.

It often happens that in a series of alloys of two metals more than one eutectic is formed. A very simple method of detecting these, and also of obtaining the complete series of alloys in one single specimen, has been used with most satisfactory results in my researches.

A small special mould of fireclay, having a cavity 2 c.m. deep and 1 c.m. square, is heated to a temperature a little below the melting-point of the metal which is most infusible. The two metals are melted in separate crucibles, and a portion of that which has the highest gravity is poured into the mould, and when the lower part has solidified the second metal is poured in drop by drop, the following drop being added when the metal in the mould has nearly solidified or become plastic. When the mould is filled, a cold metal plate is placed on the top to hasten solidification of the last portion of the metal added. When cold, if the experiment has been conducted properly, the one metal in the pure state will be found at the bottom and the other at the top, the metal between containing a complete gradation or series of alloys. One side of the little ingot is then polished, etched, and examined. The specimen so prepared constitutes a very perfect chart or map, and is the best guide to work from in making a systematic research of the alloys of any two metals, and if more than one eutectic is present it may be recognised by its characteristic appearance.

APPENDIX II.

SOLID SOLUTION.

The term solid solution has been applied to such cases, when two or more metals, in solidifying from the molten state, one or more of the metals is retained in the others, but in such a form that the highest power of the microscope is unable to detect it or them. They crystallise in a form identical with or very closely approximating to that constituent which preponderates. In a true liquid solution of salt in water, no microscope can detect any of the constituents; it appears to be homogeneous. Solid solutions of one metal in another are similar in that respect.

Sir William Roberts-Austen has kindly given me his definition of solid solution, which is as follows:—

"A solid solution is a homogeneous mixture of two or more substances in the solid state. In metals, no one has as yet worked at non-crystalline mixtures, and solid solutions of metals when crystalline are solid 'isomorphous mixtures,' or 'mixed crystals.'"

This definition is a most concise one, and certainly appears to cover every kind of solid solution.

There are, however, several kinds of solid solution:—

1st. In which one metal, from an alloy in crystallising, retains a portion of the other homogeneously diffused throughout its whole crystalline mass.

2nd. In which during crystallisation the central portion of the crystals contains less of the dissolved metal than their external boundaries.

3rd. In which the metals form a definite chemical compound, which is retained in solid solution in the excess of the metal or metals.

4th. In which the non-metallic elements form definite chemical compounds with a portion of the dissolving metal and that these remain in solid solution.

The terms "isomorphous" and "mixed," as applied to crystals, have been and still are used synonymously and are synonymous with the term solid solution in metals. The term "mixed crystals" might lead to the erroneous idea that the crystals were mixed up together but remained independent. The term "isomorphous," according to (^{20}) Professor Bauerman, can only be strictly applied to mixtures of substances crystallising in the cubic system.

There seems to be less objection to the term "solid solution." It may be applied to crystallised or non-crystallised substances, and conveys the meaning that the bodies in solution are as intimately associated as if they were in liquid solution, and that there is no separation of constituents when the fluid solution passes into the solid solution.

The expression "mixed crystals" is particularly to be avoided in metallurgical nomenclature, for the eutectics are described as eutectic mixtures, the term mixture in this case meaning an alloy or compound separated into two or more parts, whereas a so-called mixed crystal consists of a homogeneous whole.

As a rule, all metals and alloys are crystalline, therefore solid solutions of one or more metals in another may be accepted as crystalline solid solutions.

APPENDIX III.

METHOD FOR DETERMINING FREE PHOSPHIDE OF IRON.

One gramme of drillings or powdered material is placed in a 10-oz. flask. This is placed in a large beaker containing water. About 70 c.c. of 1·20 nitric acid is suddenly poured upon it. The flask is then removed and shaken up until the action of the nitric acid upon the iron has raised the temperature until it is sensibly warm, *i.e.* not more than 20° C. The flask and contents during reaction must be violently agitated, so as to avoid any local heating, and as the reaction, unless checked, would result in temperatures considerably higher than 20°, the vessel must be agitated under a stream of running water so as to regulate it. A complete solution of the iron and dissolved phosphide is generally effected in about two minutes. The flask with contents, at a temperature not exceeding 20° C., is allowed to stand on a table until no more gas is seen to arise from the residue at the bottom. This does not take more than two minutes. The insoluble matter is then filtered off through filter paper, the residue rinsed on to the filter with cold distilled water, and the filter with contents is washed with cold water. The whole of the phosphorus existing in solid solution is by this treatment obtained in the filtrate, together with a small proportion of that existing as free phosphide of iron, whilst from 90 per cent. to 97 per cent. of the free phosphide of iron is left insoluble upon the filter. The filtrate is evaporated down to a small bulk or to dryness if silica is present, and the phosphorus determined in the usual way. The filter containing the insoluble phosphide is burned off in a platinum crucible, dissolved in nitro-hydrochloric acid, and the phosphorus determined in the solution so obtained.

On making practical trials to ascertain what effect 1·20 nitric acid has upon pure phosphide of iron, it was found that the proportion dissolved depends upon the fineness of the particles of phosphide, and the length of time the acid acted upon it, and the temperature of the acid. But on treating even the finest powder in the manner described above, not more than 10 per cent. was dissolved. Whether the quantity of phosphide (of any given fineness) acted upon is great or small, provided there is always an excess of acid at the proper temperature, the proportion dissolved is constant. The following instances indicate this:—

0·1 and 0·4 grammes of phosphide were treated side by side under the conditions above named with 25 c.c. of 1·20 nitric acid at 20° C. In each case the result was the same, 0·095 was left insoluble in the one case and 0·385 in the other, or 95 per cent. of the whole in each case. The influence of long-continued action is very pronounced, for 1 gramme of finely powdered phosphide left in contact with 1·20 nitric acid for twelve hours lost 20 per cent. of its weight, but the residue was brightly metallic, and it was absolutely free from any decomposition products. An excessive quantity of acid, if employed, makes no difference provided the temperature and time elements remain constant.

In calculating the results of any analyses, allowance must be made for the solubility of the phosphide, and in the analyses given in this paper from 5 per cent. to 10 per cent. has been added to the phosphide actually found, according as the free phosphide was in a fine or relatively coarse state in the specimen examined.

Almost all other reagents, such as hydrochloric acid, sulphuric acid, chloride of copper or chloride of mercury, although they do leave more or less of the free phosphide insoluble, it is accompanied by a large proportion of the black decomposition product from the phosphide in solid solution.

Probably previous investigators have been misled in their researches by want of knowledge of this important fact.

In determining the free phosphide in presence of free carbide by this method, the latter will be more or less left in the insoluble condition, but that does not really matter, as the phosphorus in the insoluble matter will only exist as free phosphide, and is calculated into that substance.

Although the method leaves much to be desired and is far from perfect, it has rendered valuable aid in checking microscopic observations; for after considerable experience I have found, that whenever the microscope has shown that free phosphide of iron is present, even though there be very slight traces, the method has confirmed the observation.

It is important to ascertain, after the metals have been dissolved in nitric acid, that the residue is magnetic,—that is, capable of being attracted by a magnet. If it is not attracted it cannot be Fe_3P.

APPENDIX IV.

"HEAT TINTING" METAL SECTIONS FOR MICROSCOPIC EXAMINATION.

Etching polished metals with corrosive reagents is more or less liable to lead to the confusing of the constitutional and crystalline structures.

With very feeble etching, as a rule, the constituents are made visible. With long-continued or strong etching, the granular, and often the crystalline, structures are developed.

By heating polished sections of raw irons till they assume certain oxidation tints, their various constituents are differently coloured. The colouring depends on the formation of oxidation films, which form at different rates on the different constituents.

Professors Martens and Behrens were the first to use this method, and Osmond and others have employed it in the development of the constitutional structure of many alloys. It does not usually give any indication of the granular and crystalline structure, and stands before all other methods as a means of detecting the separate and individual constituents. It may therefore be called the constitutional method. It has the great advantage of not removing any of the metal, so that when the oxidation colouring has been effected, the original flat surface still remains. The specimens, moreover, are much less liable to rust than when chemical reagents are employed. The relative rates at which cementite, sulphide of manganese, phosphide of iron, pure iron, and pearlite—containing 0·6 per cent. phosphorus—assume various colours when heated, were carefully determined in the following manner:—

A slowly cooled sample containing all the above-mentioned constituents, excepting pure iron, had a fine hole drilled in it, and a piece of pure iron was inserted into this; the iron was then compressed so as to expand and perfectly fill the hole. After polishing it was bedded on sand in a porcelain capsule. The capsule was dropped into the circular opening on the stage of a Becks star microscope. A small spirit-lamp placed under the stage capsule was used to slowly heat the section. The changes of colour were carefully noted, with the following results, viz.:—

No. 1.—*Table of Heat Tints.*

With steadily rising temperatures 200° to 400° C.

Pearlite. 0·6%P. 0·75%C.	Iron.	Carbide of Iron.	Phosphide of Iron.	Sulphide of Manganese.
White	White	White	White, tinted yellow	Pale lavender
Very pale yellow	Do.	Do.	Do.	Do.
Do.	Do.	Do.	Do.	Do.
Yellow	Very pale yellow	Do.	Do.	Do.
Do.	Do.	Do.	Do.	Do.
Yellow brown	Yellow	Very pale yellow	Do.	Do.
Do.	Do.	Do.	Do.	Do.
Brown	Yellow brown	Do.	Do.	Do.
Do.	Do.	Do.	Do.	Do.
Red purple	Brown	Yellow	Very pale yellow	Pale yellow
Purple	Red purple	Yellow brown	Do.	Do.
Blue	Purple	Do.	Pale yellow	Do.
Do.	Blue	Brown	Yellow	Do.
Pale blue	Do.	Do.	Salmon	Do.
Do.	Pale blue	Red brown	Heliotrope	Brownish white
Do.	Do.	Red purple	Greenish	Do.
Pale pea-green	Do.	Purple	Yellow	Do.
Do.	Pale pea-green	Blue	Do.	Do.
Pale yellow	Pale yellow	...	...	...
White	White	...	...	...

The above table gives a good idea of the changes in colour with steadily rising temperatures.

The results obtained by heating at fixed temperatures yielded still more valuable results. The following observations were made by heating the same piece of metal as was previously used after repolishing, together with pieces of carbide of iron, phosphide of iron, and pure iron. They were placed side by side on a fluid bath of metallic tin, the temperature of which was regulated by a pyrometer.

No. 2.—*Table of Heat Tints.*

Temperature 232° C. throughout.

	Pearlite. 0·6%P. 0·75%C.	Iron.	Carbide of Iron.	Phosphide of Iron.
1 min. . . .	Very pale yellow	White	Very pale yellow	White
4 min. . . .	Yellowish brown	Very pale yellow	Pale yellow	Do.
10 min. . . .	Do.	Darker yellow	Do.	Do.

No. 3.—*Table of Heat Tints.*

At constant temperature of 280° C.

	Pearlite. 0·6 % P. 0·75 % C.	Iron.	Carbide of Iron.	Phosphide of Iron.
1 min. .	Brown	Yellow	Brownish yellow	White
2 ,, .	Purple	Red brown	Do.	Do.
3 ,, .	Deep purple	Brown	Do.	Do.
4 ,, .	Blue	Purple red	Do.	Very pale yellow
6 ,, .	Do.	Purple	Orange brown	Pale yellow
11 ,, .	Do.	Blue	Red brown	Pale salmon
15 ,, .	Pale blue	Do.	Burnt sienna red	Do.
30 ,, .	Paler blue	Paler blue	Purple brown	Heliotrope

No. 4.—*Table of Heat Tints.*

At constant temperature of 326° C.

	Pearlite.	Iron.	Carbide of Iron.	Phosphide of Iron.
1 min. .	Purple red	Red	Yellow brown	Very pale yellow
2 ,, .	Deep blue	Purple red	Red brown	Pale yellow
3 ,, .	Do.	Do.	Do.	Do.
4 ,, .	Do.	Do.	Do.	Do.
5 ,, .	Do.	Deep blue	Do.	Pale salmon
6 ,, .	Paler blue	Lighter blue	Purple red	Salmon
7 ,, .	Pale sea-green	Very pale blue	Purple	Do.
8 ,, .	Do.	Do.	Do.	Do.
9 ,, .	Pale yellow	Do.	Do.	Purple
10 ,, .	Do.	Do.	Do.	Heliotrope

In high carbon steels and white irons the free phosphide is always accompanied by cementite or carbide of iron, and it is easy to distinguish them by heating to 280° C. for ten to fifteen minutes. After such treatment the cementite will be red brown after each heating, whilst the phosphide will be pale yellow after ten minutes' heating, and salmon colour after fifteen minutes. On continuing the heating, the blue at first assumed by the phosphide of iron is quite different from that of any of the other constituents. It may be described as heliotrope in tint.

When no cementite is present, it is advisable to heat at 280° C. along with specimen chips of phosphide and white Swedish pig iron and pure iron, and watch the tints on these three indicators. As soon as the white iron has assumed a brown colour, the phosphide a pale yellow or salmon tint, and the iron a fine blue, the specimen is at once removed and examined for the phosphide of iron.

It has not been exactly determined what the effect is of varying quantities of dissolved silicide of iron. That it does make a great difference has been proved, a fact which must be kept in view in examining high silicon pig irons.

The effect of chromium, aluminium, manganese, nickel, and tungsten in determining the tints has not yet been ascertained.

Some alloys contain a fusible constituent which melts and exudes from the surface before any oxidation can take place, therefore oxygen is not available in such cases. Different tints, however, can be obtained by heating these alloys at low temperatures in an atmosphere containing slight traces of iodine, bromine, or hydric sulphide. In using these reagents the specimen is heated in a box fitted with a glass lid, and air which has passed over iodine, or which contains traces of bromine or H_2S, is forced over the hot metal. The constituents then colour differently, and may be distinguished from each other.

The general method of tinting the specimens when they are heated may conveniently be called the "Heat Tinting Process," and the chemical symbol of the particular reagent used may be added as prefix, thus:—

Heat tinting (O) oxidation films being formed.
,, (I) iodide ,, ,,
,, (Br) bromide ,, ,,
,, (H_2S) sulphide ,, ,,

In marking the microscope slides the following abbreviations may be used:—

HT(O), HT(I), HT(Br), HT(H_2S).

Special precautions are necessary in preparing the polished surfaces. If, after leaving the polishing block, they are at once heated till the tints appear, they will not be true, as the moisture in the porosities, when it evaporates, will affect the surface. It is necessary to make a preliminary heating to about 120° C., and remove from the source of heat, and rub it whilst hot on a clean dry hair buff or piece of flannel. It is then at once re-heated to the proper temperature, and as soon as the tints have developed it is placed at once on a bath of mercury to cool it rapidly and avoid further change.

SPECIAL ELECTRICAL APPARATUS FOR "HEAT TINTING."

By arrangements such as have already been described, the tinting can be done under the microscope by the flame of a spirit-lamp, but the stage becomes highly heated, which is very objectionable. I have, therefore, devised a simple electric heater, which can be placed on the microscope stage, and the progress of the tinting observed. The following description, with the assistance of Plate I., will make the construction of the apparatus intelligible.

The bed is of ebonite, and on this two strips of brass are screwed, one on each side of the upper surface. To these are attached the binding screws AA.

The carrier consists of a small 1-inch porcelain capsule, on two opposite sides of which a closely fitting sheath of brass is secured. These, when it is placed in position, form the contacts with the two conducting brass strips on the bed.

The bottom of this capsule is filled with magnesia made plastic with a solution of chloride of magnesium. A platinum spiral is bedded upon this, and the terminals connected to the brass sheaths. Over the wire is painted a thin layer of silica paint, made by mixing silicate of soda and silica to the consistency of a thin paste, after which the apparatus is ready for use.

The porous magnesia under the wire is a good non-conductor, and practically no heat passes to the microscope stage.

The capsule is quite loose, and can be removed from its bed or swivelled to any angle, so that a specimen placed upon it can always be made to have its polished surface parallel with the stage.

The current can be switched off as soon as the proper tinting is obtained.

This simple apparatus will no doubt be found to be very useful where there is a supply of electricity.

APPENDIX V.

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DISCUSSION.

The **President** invited discussion on Mr. Stead's most interesting paper. How long and patiently Mr. Stead had worked at this subject, and how elaborately his theories were supported, was evidenced by what they had heard that day.

Mr. **Henri de Wendel**, speaking in French, said: One would have to be an eminent micrographist and accustomed to follow all the works on the micrography of steel in order to be able to discuss Mr. Stead's work. I do not know enough about micrography to be able to enter into the details of the question. But it is none the less true that Mr. Stead has made considerable progress in it. Up to now we have only known the micrographical structure of steel as it has been revealed by the more or less hard or soft polishings, and we have here quite an entirely new method, which gives us a description of what passes in the steel like the description of a geographical chart. The modifications which are produced when you bring the metal to such and such temperature make one see that the bodies move about in the steel as you, if you permit the expression, will move about in the Exhibition, all in good time. They meet together, separate, and then join one another again. What is most remarkable in this work is the enormous amount of work, the number of analyses and observations that have been necessary to achieve these results, simple as they seem to-day, and they have only been brought about by a labour which has certainly lasted some years, and for which we have to thank Mr. Stead, as well as all those who have worked with him.

Dr. **Stansfield** said he had not been able to fully study Mr. Stead's paper, and he must therefore limit himself to one or two questions with respect to it. First of all, with regard to the diagram showing the idiomorphic crystals, he was not quite sure whether Mr. Stead meant that they were crystals of phosphide of iron or of the eutectic. If the latter, it was strange that they should exhibit such beautiful crystalline forms. With respect to the diagram under the head of phosphorus and iron, he had followed with great interest Mr. Stead's graphic description, and was sorry that he stopped so soon. He had wished to hear from Mr. Stead what relation there was between the crystals of Fe_3P and Fe_2P when they occurred together. Thus, for example, the solid solution of iron passed into Fe_3P through the intervention of a eutectic. Was there anything of the same kind between the compounds Fe_3P and Fe_2P? Some indication of this should appear in the curve of fusibility of the metals. He should like to know whether Mr. Stead obtained this curve in the usual method by taking cooling curves, as had so often been done in the case of carburised iron. He had only to add how much they were all obliged to Mr. Stead for his extremely patient explanation of the very difficult subjects he had been considering, and his own admiration for Mr. Stead's most beautiful photographs.

Mr. **ALBERT LADD COLBY** (South Bethlehem, Pennsylvania) wished to say a word with reference to Mr. Stead's suggestion that a committee of practical men from steelworks be formed to study the practical side of the question, and, if possible, to make practical deductions from this theoretical study of the effect of phosphorus on iron and steel. He thought the suggestion an excellent one, and hoped that when the Committee was formed, that American steelworks would be represented, for they would be very glad to aid in such an important investigation.

Mr. **EDWARD RILEY** (London) said that in years gone by there was a very common iron in South Wales which had pea-like exudations from the high phosphorus pig iron liquating out.

Sir **THOMAS WRIGHTSON**, Bart., M.P., asked, as to the welding of the phosphide, whether there was any pressure brought to bear upon the materials, and whether any tests were made to see that the junction had been absolute?

Mr. **STEAD** in reply said, with regard to the question of Dr. Stansfield about idiomorphic crystals of Fe_3P, he thought he had stated that they were not eutectic, but actual solid crystals of phosphide of iron. They did not contain two separate constituents. The systematic thermal study of this question was reserved for future investigation. The curve shown was not more than a diagrammatic representation of what approximately took place. The thermal results would be presented when he had completed his plant for making perfect records. He was at present putting in massive concrete foundations on which to place the pyrometer and photographic apparatus, and he looked forward to the thermal part of the research with pleasing anticipation. Their President had the advantage of working in the cellars at the Mint, where there was little vibration, and his records could not be more perfect than they were, and he (Mr. Stead) hoped to be able to get as good work at Middlesbrough.

With regard to the other question of Dr. Stansfield about compounds in Class IV., he had not analysed all the crystals separated from mixtures containing between 15·5 per cent. and 21·5 per cent. phosphorus. That containing about 18 per cent. phosphorus he had most carefully examined chemically, and he found it to contain about equal parts of Fe_3P and Fe_2P. It is the thermal study of this class which will probably yield the most valuable results.

He was glad to hear that Mr. Edward Riley noticed the pea-like exudations from high phosphoretic pig irons. He thought he must have done, but could not find any published work in which the fact was recorded.

Sir Thomas Wrightson had asked if the metals needed pressing together when welding iron by phosphide to effect union. It did not matter whether the pieces of metal were laid side by side or placed one on the top of the other, because the phosphide of iron behaved like solder. It ran between flat surfaces by capillary attraction and then diffused into the metal, and the excess ran out, but there was no free phosphide of iron left at the junction if sufficient time was given for it to escape. He did not think that the joint was stronger than a braised joint, but he had not so far made any mechanical tests.

The remarks of Sir T. Wrightson referred to experiments described at the meeting, which had been made since the paper was printed, and to which there is no reference in the text.

The nature of the experiments was as follows, viz.:—Several pieces of sheet iron were piled one on the top of the other, but between each piece a little phosphide eutectic in powder was laid. The pile was then heated in a crucible to about 1000° for ten minutes, and was allowed to cool. On examination, the pieces were found to be perfectly welded together. The phosphide eutectic had become liquid, and had united with the surface of the iron, and the excess of the fluid portion had run out at the sides, leaving perfect junctions of solid solution of phosphide in iron. On polishing the sections, the joints were found to be relatively harder than the unaltered metal, and on heat-tinting coloured in advance of the pure iron. When the iron had assumed a yellow tint the junctions were a beautiful blue colour.

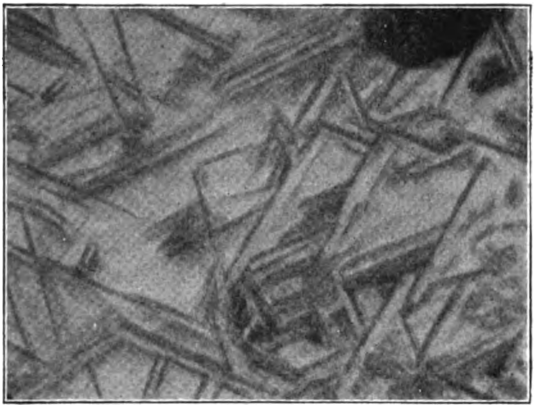
CORRESPONDENCE.

Mr. E. H. **Saniter** sent the following contribution:—

I have read Mr. Stead's able and exhaustive paper with great interest, and must thank him for supplying us with so many new facts and such beautiful photo-micrographs, and particularly for the new and gorgeous application of the heat-tinting process, which has been so useful in making his research complete. Any one who has seen one of his heat-tinted objects under the microscope will not soon forget it.

In his remarks on "crystalline form," Mr. Stead states that he heated a metal containing 1·15 per cent. of phosphorus, and argues that, as the cleavages were the same before as after heating, no allotropic change had taken place. This may be true, but the reasoning does not appear conclusive, as the metal would naturally revert to its former state on cooling. The photo-micrograph marked A. may throw some light on this point. This is taken from the face of a cube of iron containing 0·35 per cent. of phosphorus and no carbon, etched in calcium chloride at a bright red heat. The sides of the cube were parallel with the sides of the photograph. The peculiar structure here developed, showing markings of plates at various angles and not parallel to the sides of the cube, would seem to indicate a change of structure due to heat in iron containing 0·35 per cent. of phosphorus. The structure has a character of its own, and does not resemble any of the hot structures of pure iron or carbon and iron which I have previously shown. In connection with this matter it may be stated that calcium chloride attacks massive Fe_3C much more rapidly than Fe_3P at a red heat, and that therefore they can be distinguished by this method.

As is already known, certain interesting and as yet unexplained changes take place in nickel steel, and I believe also in certain chilled carbon steels when cooled down in liquid air; it might therefore prove instructive to submit one of Mr. Stead's solid solutions of phosphide in iron to a similarly low temperature, to ascertain if any phosphide might be caused to separate and form a pearly eutectic. In connection with this it should be remembered that phosphoretic irons become more brittle with excessive cold.



A.—Carbon, nil; phosphorus, 0·35.
Hot structure.

With regard to the figures, 0·64 per cent. carbon and 0·62 per cent. phosphorus, given in my remarks cited, it is interesting to see how often the latter figure comes up in Mr. Stead's results. I feel inclined to consider them as the state of equilibrium brought about in iron containing carbon and phosphorus in excess, when very slowly cooled.

I am inclined to agree with Mr. Stead that too rapid cooling and want of mass has prevented his results on page 87 arriving at a state of equilibrium.

Further, a possible error of 3 per cent. in estimating the free Fe_3P, or variation in the sample, quite alters Mr. Stead's calculation in Part II. For instance, if we take the phosphorus as free Fe_3P to have been 1·45 instead of 1·40, we get the following figures:—

	Per Cent.		Carbon per Cent.	Phosphorus per Cent.
Carbide of iron, massive	48·4	=	3·23	...
Pearlite containing { ·64 per cent. C. / ·62 per cent. P. }	42·0	=	0·27	0·26
Phosphide of iron (free)	9·3		...	1·45
	99·7		3·50	1·71

showing that a very small analytical error would make Mr. Stead's figures agree with mine; but I do not argue from this that either Mr. Stead's or my calculation are valuable, but that under the circumstances they are not convincing.

Let me now apply a similar calculation to No. 3 sample, containing 0·18 per cent. of carbon:—

	Per Cent.		Carbon per Cent.	Phosphorus per Cent.
Pearlite containing { ·64 per cent. C. / ·62 per cent. P. }	24·0	=	0·18	0·16
Phosphide of iron (free)	3·8	=	...	0·59
Solution of phosphide in iron containing 1·75 per cent. of phosphorus . .	72·2		...	1·26
	100·0		0·18	2·01
				1·77
Showing a deficiency of . .				0·24 per cent.

Here again the calculation disagrees with the actual results. It is difficult to understand why so large a quantity of phosphide as is represented by 0·59 per cent. of phosphorus should have been thrown out of solution by 0·18 per cent. of carbon, as the rapid cooling is not likely to assist in this. It would appear that a very small amount of carbon disturbs the solid solution point of 1·75 per cent. of phosphorus.

The further fusing experiments and the cementation experiments are exceedingly interesting, and confirm the variations of the amount of free phosphide caused by varying carbon and phosphorus contents under varying conditions, and it is this variability in the behaviour of phosphorus which has no doubt caused different observers to disagree as to the effect of a given percentage of this element on steel.

Mr. Arthur Wingham writes:—Is it not possible that the films of the eutectic have a disruptive influence on the metal, apart from their forming lines of weakness? The formation and final solidification of the eutectic in the solid surroundings might exert an internal pressure, which only awaits another or an outside influence to assert itself. Certain it is that there is a mechanical pressure on the interior of the mass of metal, and Mr. A. Stansfield has just shown that this may be the cause of the non-formation of graphite in the interior of a carburised iron under those conditions which produce it towards the exterior, where the pressure is less. Hence there must be an internal strain of some kind. Probably, in the case of eutectic mixtures, actual or incipient release of the constituents takes place in spite of this pressure of the mass, producing a pressure tending to disrupt the metal. Given a shock sufficient for this force to assert itself, and fracture takes place. Brittleness, of course, is influenced by many conditions, which may act separately or in conjunction one with another. It is attributed frequently to the crystalline structure, but a crystalline metal is not always easily fractured. Take, for instance, the metal tin; it is highly crystalline, but can be bent backwards and forwards many times with its well-known "cry," especially, I believe, if fairly pure. A drop of mercury rubbed across it will render it extremely brittle, which may or may not be due to the formation of the eutectic amalgam, and its acting in conjunction with the mechanical pressure of the mass, and perhaps also with a pressure exerted by itself. This would seem to be supported by the tendency of the eutectic mixture to squeeze out when a metal is heated to a temperature just above the melting-point of that mixture, the expansion of the metal due to the heat surely affecting the mass as a whole, rather than the individual crystals one against the other. The fracture pursuing the course of the cleavage planes is one of the incidental effects which renders the fracture more easy. It is possible that the cleavage planes themselves might be under the influence of microscopical, or perhaps molecular, films of eutectic.

The acceptance of the above idea, or even only that there may be some change of state ready to take place in the metal, may lead to the explanation of why a metal bar or shaft, after working or running safely for years, should suddenly break under exactly normal conditions, and without any extra strain being put upon it. The constant vibration or oscillation may tend to assist such change, so that in the course of time the internal pressure, assisted perhaps by temperature fluctuations, may produce a flaw, or, given a flaw, may help to finish the fracture. In this direction the test for segregation mentioned in this paper should be one of great practical importance.

I should like to inquire if the heat-tints given for the pearlite containing 0·6 per cent. P and 0·75 per cent. C would be the same with a pearlite containing no phosphorus? If they are not, then the present material is a body different to pearlite, and its name should be altered or qualified. Under any circumstances, I think some indication of its containing phosphorus should be given. Taking pearlite as (21 Fe + Fe_3C), the figure 0·75 per cent. C would produce about 85 per cent. of it, leaving 15 per cent. of a substance containing about 4 per cent. of phosphorus, or say 25 per cent. Fe_3P, which, according to the author, should also show a pearly structure. It is hardly sufficient, however, at the present time that a definite name like pearlite be given to a number of substances because they are pearly in appearance. I suggest that the present pearlite should be called phospho-pearlite, to distinguish it from what is now understood to be pearlite, or phospho-carbo-pearlite, in anticipation of the possible increase in the members of the pearly family. Is there not room for more exactness in metallurgical nomenclature? I do not mean in foundries and works, where it is hopeless, but in the scientific development of the subject. It is becoming more and more involved every year, and it cannot be made too precise and consistent in consideration of its future study. For this reason I think the appendices to the paper considerably enhance its value.

Mr. STEAD forwarded the following reply to the correspondence on his paper:—

In answer to Mr. Saniter's remark with reference to the experiment on crystalline form referred to in the paper, I have shown in a paper read before this Institute that pure iron in large crystalline masses, on heating through 1000° C., breaks up and re-crystallises into a large number of smaller crystalline grains, and that this breaking up is coincident with the thermal arrest, Ar_3. It is not denied that in the case of pure iron these coincidences do occur. It is also admitted by Mr. Osmond and Professor Arnold that steel containing high phosphorus prevents the thermal arrest, but it has not been shown previously that the coincident re-organisation of the structure did not occur, although it was anticipated that it did not, and the object of the experiment referred to was to determine this point; the result confirmed the anticipation. It is very generally admitted that the arrest point, Ar_3, indicates an allotropic change, and that if there is no arrest there is no allotropic change. I do not mean to leave the impression that because the allotropic change takes place in pure iron by heating through 1000° C., that on cooling down the metal would remain in the changed state. It is universally admitted that it does not.

The photograph submitted by Mr. Saniter is very interesting, as the developed markings do not correspond with the principal cleavages of the crystals. As to what significance this structure has is not evident. I have obtained a similar kind of structure on acid, etching a piece of pure iron. Much more study is required before we can explain what they indicate.

I have not experimented with phosphoretic material by quenching in liquid air. Indeed, I have not exhausted the study at normal and accessible temperatures, and much more would have to be done before I venture into the region referred to by Mr. Saniter.

I agree that steel containing 0·64 per cent. of carbon and 0·62 per cent. of phosphorus may represent a state of equilibrium when it is *very* slowly cooled, but it should be pointed out that it is highly probable that if the cooling was done more rapidly or more slowly, the ratio of carbon and phosphorus would vary very considerably.

In answer to the suggested possible error of 3 per cent., I quite admit Mr. Saniter's position, as showing that very slight variations in the analyses of either Mr. Saniter or his own would lead to a modification of the conclusions. The point raised is useful, as showing the necessity of further proofs.

It is pointed out by Mr. Saniter that a unit of carbon throws out a greater proportion of phosphorus from a saturated solid solution than from one containing less phosphorus. The reason for this is not far to seek, for, as has been shown in the paper, the phosphorus is feebly held in solution in the saturated compound, and very slow cooling from a high temperature is sufficient to cause some of it to separate even without any carbon at all.

In answer to Mr. A. Wingham with regard to the question of internal pressures and strains when metals solidify, it is possible that films of the eutectic may have a destructive influence on the metal. It must not be forgotten, however, that after the formation of the eutectics, in cooling down to the normal atmospheric temperature, the molecules of all the constituents are still active and mobile, and apparently more or less migratory and inter-diffusive. When the cooling is exceedingly slow, any disruptive or strained position most probably will be, in such cases, neutralised by the molecular re-adjustment of the particles.

It is certain, as Mr. Wingham mentions, that the molecular pressure on the mass of cooling pig iron is responsible for the formation of the white portions in the centres of certain pig irons. A most notable example of this was given by myself in the discussion on Sir Thomas Wrightson's paper on "Some Physical Changes occurring in Iron and Steel at High Temperatures," read before this Institute in 1880.

I have long wished for the time and opportunity to determine exactly what takes place when minute quantities of mercury causes brittleness in tin or zinc. I am inclined to believe it forms a brittle alloy along the planes of the cleavage. It does not appear ever to have been stated that because a metal is crystalline it is therefore brittle. All metals in commercial use are crystalline. Brittleness has been shown to take place in certain pure irons in which the general orientation of the crystalline axes of the crystalline grains, with relation to the exterior surfaces, were practically all in the same direction. In such cases fracture was readily effected along the general directions of the principal cleavages, but in no other directions.

I am far from knowing all that could and will be learnt eventually about eutectics and their influence upon structure. So far, however, I have not been able to detect any eutectic between the cleavages of pure iron, even in such iron as is easily broken.

The phospho-pearlite, containing 0·60 per cent. of phosphorus, when hot will dissolve much more than 0·75 per cent. of carbon in the state of carbide of iron, Fe_3C. The 15 per cent. substance Mr. Wingham refers to, other than $(21\ F_2 + Fe_3C)$ as containing 4 per cent. of phosphorus, does not appear to be possible in the light of revealed facts. If in the cold state the 15 per cent. contained 4 per cent. of phosphorus, there would be some free phosphide, which apparently is absent. It appears better to regard phospho-pearlite as a mixture of $\frac{75 \times 100}{6·666} = 11·2$ per cent. of carbide of iron in juxtaposition with 88·8 per cent. of phospho-ferrite containing about 0·66 per cent. of phosphorus.

There had been no previous attempts made to give the various pearlites qualifying titles. There are pearlites in steel which contain manganese, silicon, chromium, nickel, &c., and they more or less have an influence on the rate at which the pearlite takes colour on heating.

Ordinary pearlite takes temper "tints" more slowly than the phospho-pearlite. The carbide in each behave alike, but the phospho-ferrite colours more rapidly than pure ferrite. I have no objection to the term phospho-pearlite. The difficulty is to decide at what point the distinctive term should be applied. If a pearlite with 0·6 per cent. phosphorus is called phospho-pearlite, would it be justifiable to call it so if the phosphorus was 0·3 per cent., or even 0·1? In silicide and other steels at what percentage must the qualifying term be applied?

I agree with Mr. Wingham that it is very desirable that a correct nomenclature for metallography should be arranged, and would suggest that a committee of metallographers should be formed to consult, and draw up proposals which might then be sent to every known metallographer for criticism. Some such plan would no doubt lead to good results.

IRON AND STEEL AT THE UNIVERSAL EXHIBITION, PARIS, 1900.

By Professor H. BAUERMAN, Ordnance College, Woolwich.

The following paper, which has been prepared mainly for the use of the members of the Institute visiting the Exhibition during the meeting, is intended to serve as a summary guide to the more prominent exhibits, and not as a complete analysis of the whole collection, for which purpose more space would be required than could reasonably be asked for. It may, however, be useful to say a few words, by way of introduction, on the general principles of arrangement adopted, using, by way of reference, the excellent plan attached to the detailed programme of the meeting.

1. *Classification.*—According to the scheme adopted by the Commission of the Universal Exhibition, the subjects of mining, metallurgy, and metal manufactures are included in Group XI., which is subdivided into the following classes:—

Classe 63. Exploitation des Mines—Minerals and processes of mining.
Classe 64. Grosse Métallurgie—Smelting and heavy forge and foundry work.
Classe 65. Petite Métallurgie—Small metal-work, hardware, &c.

The bulk of the exhibits in these classes are to be found in the Palais des Mines et de la Métallurgie, which occupies the northern end of the eastern part of the twin building on the Champ de Mars. This covers about seven acres, the space being nearly equally divided between France and foreign countries; and the same arrangement is followed in the gallery, where, however, the French and foreign sections are separated by the retrospective or centennial exhibition. The mining exhibits in Class 63 are to be found mostly along the northern and eastern walls of the ground floor; those of the smaller metallurgy, Class 65, are on the western side, and Class 64, with which this notice is principally concerned, occupies the central position; the more prominent exhibits of the ironworks of the Loire, the central regions, the Meurthe and Moselle, and the North, being grouped in the middle octagonal hall, about the large temple-like trophy of brass, copper, and other metal pipes and plates of the Compagnie Française des Métaux. In the foreign sections no such systematic arrangement is followed, and in some instances the objects are placed in other buildings in different parts of the ground. Some of the large French steelworks duplicate their exhibits in the Pavilion of the Army and Navy on the Quai d'Orsay, and other contributors have special buildings of their own, such as Messrs. Schneider & Co., and Messrs. Vickers, Sons, & Maxim, in the same vicinity.

The development of ironmaking in France since 1889 has, speaking broadly, followed upon similar lines to those of this country, with the result of concentrating the output in the "Minette" region of the north-east, which represents the Cleveland and oolitic ore regions of England, and in a less degree to the neighbourhood of the coalfields and seaports, the latter class of works being largely dependent upon foreign countries for ore, and in some cases for fuel supplies. In addition to the minette ores, which are essentially phosphoric, and serve for basic steel and foundry uses, high-class manganiferous ores of great purity are mined in some quantity in the mountain regions of the Alps and Pyrenees, the working and transport being accompanied by the difficulties common to such regions. These ores are mainly used by the crucible and fine steel makers of Saint-Étienne and the South. The famous pisolitic and concretionary ores of Berri and the central plains, although of minor importance as regards quality, still maintain their reputation for the production of strong malleable iron and special castings, both for industrial and ornamental use.

The present condition of the ore-mining industry in the Eastern region is well illustrated by the collection of maps, sections, bore cores, and other specimens contained in the exhibit formed by Mr. F. Vilain for the "Collectivité des Exploitants de Minerai de Fer du Meurthe," a body which includes eighteen iron-smelting firms having works in the neighbourhood of Longwy and Nancy. From this we gather that the workings of oolitic ore are mainly concentrated in two areas known as the basins of Nancy and Briey. In the former the mining area is about 72 square miles, the ore-bearing formation being about 35 feet of marls and limestones, containing three beds of mineral varying considerably in quality, the best ore being got from the upper bed in the north, and from the lower one in the south, the workable thickness varying from 8 to 14 feet, according to the nature of the different beds. The output of this district was 1,700,000 tons in 1899.

In the Briey basin, which is the more important region, with a conceded area of 120 square miles, there are no outcrop mines, the ores being all deep-seated; but they have been systematically proved by more than 150 borings, at a cost of about £120,000. The principal deposit, the so-called grey bed (*mine grise*), which resembles unweathered Cleveland or Northamptonshire stone, contains 35 to 42 per cent. iron, about 0·9 per cent. phosphorus, 7 to 15 per cent. lime, and 5 to 7 per cent. silica, the waste constituents being in such proportion as to require a certain addition of siliceous flux, which is supplied by some of the leaner ore of the associated yellow, red, and black beds. The grey bed varies between 7 and 25 feet in thickness, and the depth below the surface from 250 to 850 feet. The quantity of ore contained in the region is estimated at about 2000 million tons, about one-half of which may be got by systematic mining. The most active working centres at present are at the northern end, in the district of Longwy and Villerupt, with an output in 1899 of 2,400,000 tons. The total production of iron ore in France is about 5,000,000 tons, the Meurthe and Moselle region contributing over 80 per cent., and in the same year the blast-furnaces of that department produced 1,576,000 tons, out of the total make of pig iron of 2,576,000 tons. It is expected, however, that with increased development of the mines and facilities for transport, a total make of 2,500,000 tons in the department may be attained in the next ten years. Considerable difficulties have been experienced in opening the deep mines, owing to the large quantity of water encountered in sinking, which, in some instances, has led to the necessity of adopting the Poetsch system of freezing the water-bearing strata around the side of the shaft.

The ores of the Pyrenees are represented in a group of exhibits placed near the north-east corner of the building, contributed by the Société des Mines de Fer de l'Ariège, and a general collection for the department. These are manganiferous brown ores resulting from the weathering of spathic ores such as were formerly used in the now extinct Catalan forges of the district. Among the most productive mines is that of Las Indes (Mines de Balere) in the Eastern Pyrenees. These are contact deposits between the granite of Mont Canigou and limestones and schists which have been followed for about a mile. The output, about 90,000 tons per annum, is partly red hæmatite and partly spathic ore, the former being found at the contact with limestone, and the latter with schists. The hæmatite contains iron 54, manganese 3, and silica 4 per cent., and the carbonates average about the same yield when calcined. The mines, which are in a difficultly accessible position, are connected with the railway by a rope-way with a fall of 3920 feet in about 5½ miles. Other iron mines of the Ariège are those of Foix la Bastide de Serin and Saint-Gisors, producing brown iron and manganese ores and bauxite. These, together with the massive carbonate of manganese of Las Cabesses, which occurs in irregular deposits in Devonian limestone, will be found in a collective exhibit of the Mines de Fer de l'Ariège.

The iron ores of the older sedimentary rocks of Normandy and Brittany are represented by the Mines de Saint-Remy Calvados, who show a model of the workings in addition to samples of the ore, which is a compact or somewhat oolitic mineral of a bright red colour. The deposits, included between the Armorican sandstones and Angers slates of Lower Silurian age, are comparable as to position to the Merionethshire ore, with the difference that the ore is a hæmatite and not magnetic. The bed has been extensively disturbed since its deposition, and, judging from the model, has been extensively worked by the pillar-and-stall system, a large proportion being left as support of the roof.

The alluvial ores of Berri and Champagne are not specially represented, but samples of these minerals may be seen in the exhibits of the Val d'Orne Company, and other makers of ornamental castings, for which they are specially suited.

The great ironmaking region of Saint-Étienne is very largely represented, the exhibits being grouped separately, but with a certain uniformity of arrangement, about the central octagon, under the title of Collectivité de le Loire, which includes the following works:—Saint-Chamond, Marrel Brothers, Firminy, Unieux, Brunon & Valette, Saint-Étienne, and Claudisson & Co. Prominent among them is the large collection of the Compagnie des Forges et Acieries de la Marine et des Chemins de Fer, proprietors of the well-known works of Saint-Chamond, Asailly, Rive de Gier, and Givors, in the neighbourhood of Saint-Étienne, and the Forges de l'Adour at Le Boucau, near Bayonne. This includes iron and steel work for uses in military, naval, and railway service, and is supplemented by a large show of ordnance and armour-plates in the naval and military building on the Quai d'Orsay. The great extent of these collections, which require a catalogue of 40 quarto pages for their description, renders it impossible to give even the most summary analysis of their contents, further than to state that Saint-Chamond contributes heavy castings and forgings for artillery, with models of the 100-ton ingot used for naval guns, one of the castings for a 6000-ton forging press lately erected, a rough hollow forging of 26 tons for the tube of a 12-inch naval gun, worked under a steam-hammer upon a mandrel, several finished gun forgings of smaller sizes, a fine collection of tested locomotive and waggon tires, and an interesting series of fractures and test-pieces of structural steel of all kinds between 25 and 48 tons tensile strength. Among these the special steel of Saint-Chamond, containing both chromium and nickel, ranges, according to hardness, between 41 and 48 tons in tensile strength, with 19 to 23 per cent. elongation, and the 26 per cent. nickel steel gives 46·5 tons with 65 per cent. elongation on a length of 4 inches. The basis of these objects is open-hearth steel, using for the bath Sardinian magnetic, Spanish, and Algerian ores, which, when necessary, is specially refined to reduce sulphur and phosphorus to a maximum of 0·01 per cent., and as malleable material, iron puddled from the same class of pigs in a rotatory furnace with separate melting bed, taking 20-cwt. charges and producing about 8½ tons of puddle blooms in twenty-four hours. For ordnance, the ingots are reduced by forging to one-fourth of their original cross section, and in weight by 50, or, in some cases, 60 per cent. before turning. The metal is from 25 to 38 tons tensile strength, with a minimum elongation of 18 per cent. when soft, and 12 to 14 per cent. when hardened. Several kinds of plated and rotatory towers for land fortifications are exhibited in the Artillery Section, and in connection with these it is interesting to note that the experience of the Company has led them to prefer iron armour for such works in preference to a harder but more brittle metal of greater tensile strength.

The Asailly Works contribute crucible steels for tools and cutlery, including special chrome and tungsten self-hardening kinds, "natural" or puddled steel, drawn directly from blooms and piled as single and double shear, and special crucible steel castings; and the crucible and brickworks at the same place send firebricks and moulded pieces in clay, silica, and magnesia, besides samples of steel melting-pots.

The forges at Rive de Gier are represented by a shaft with a single crank of 11 tons, of the kind made for the new transatlantic packets *Lorraine* and *Savoie*, and one with three cranks for the cruiser *Isly*, also railway axles and wheel centres of the patterns used by the principal French railway companies.

The Boucau exhibit contains sections of rails, fish-plates, joints, angles, and other structural bars, and examples of two kinds of annular spring-keys, used instead of wooden trenails by those companies in France that adhere to chair-rails. The ingenious method of making these keys from flat bars will be remembered by those members who visited the Boucau works on the return of the *Ormuz* from Spain in 1896.

The products of the Boucau furnaces are also well represented. They include foundry irons with a specially desulphurised class, spiegel and ferro-manganese with 40 to 80 per cent. manganese, ferro-chrome with 60 to 70 per cent. chromium, and ferro-tungsten with 80 per cent. tungsten.

Messrs. Marrel Brothers of Rive de Gier display a series of heavy forgings for artillery and projectiles, as well as armour-plates, among them a single crank shaft roughed down from a 50-ton ingot, and a surface-hardened armour-plate of 210 mm. for the battleship *Henri IV.*, tested by a projectile of 194 mm. with striking velocities of 583, 683, and 710 metres per second.

The Forges and Steelworks of Firminy contribute, besides tubes and machinery castings, a finished connecting rod in nickel steel for a new transatlantic steamer, railway tires up to 10 feet 3 inches diameter, a steel shell of 420 mm., which penetrated a 550 mm. steel armour-plate, and tool steels of various kinds, including one of a specially hard character for which the name of "*acier Satan*" has been selected.

In the exhibit of the Forges and Steelworks of Saint-Étienne, a method of making heavy projectiles from conical steel ingots, shown in different stages of transformation, as well as a system of compressing steel ingots, are specially noticeable, besides some fine examples of large hollow forgings and plates for gun-shields.

Messrs. Jacob Holtzer & Co. of Unieux have a large and very varied exhibit of objects almost exclusively in crucible cast steel. The basis of the manufacture is charcoal pig iron from Ria in Corsica, which is partly converted into steel by puddling, but principally by cementation and fusion in crucibles. Gas-melting furnaces are used containing 30 to 32 crucibles, each one admitting of the production of ingots up to 6 tons. Among the most notable objects, in addition to the famous Holtzer projectiles, are castings for the framing of T. B. D. engines, cylinder cones for large marine engines, deck and shield plates for naval guns, and a remarkable series of tests of steels with varying proportions of chromium from 5 to 30 per cent., the carbon being kept constant at 0·4 per cent. The mechanical properties of these alloys are shown in the following table:—

Chromium.	Condition.	Elastic Limit.	Breaking Stress.	Elongation.	Contraction.*
Per Cent.		Tons per Sq. Inch.	Tons per Sq. Inch.	Per Cent.	
5	Annealed . . .	17·8	31·8	24·0	0·240
	Hardened and tempered	48·8	55·2	12·0	0·370
10	Annealed . . .	22·9	42·0	21·5	0·440
	Hardened and tempered	42·4	54·3	12·0	0·536
15	Annealed . . .	25·4	45·3	18·5	0·500
	Hardened and tempered	48·8	58·1	11·5	0·546
20	Annealed . . .	21·2	36·1	21·5	0·465
	Hardened and tempered	27·6	40·3	19·5	0·515
25	Annealed . . .	29·8	42·2	18·0	0·621
	Hardened . . .	27·6	40·4	20·0	0·500
30	Annealed . . .	31·8	41·6	19·0	0·620
	Hardened . . .	28·8	39·0	19·0	0·650

* Ratio of fractured to original section.

These alloys have been made with pure chromium produced by the reduction of chromic oxide with aluminium, a very fine example of the metal being exhibited with the specimens.

Messrs. Brunon & Valette of Rive de Gier send a large collection of drawn and stamped steel-work, including special forms of wheel centres for railway and tramway use, drawn tubes from 0·2 to 24 inches in diameter, compressed air and gas reservoirs, and fittings for overhead electric tramways. This is supplemented by a considerable exhibit of projectiles and artillery appliances in Classes 116 and 118.

The exhibit of the Chambon-Feugerolles Steelworks of Messrs. Claudinon & Co. contains some interesting features, including the details of a new method of forging tubes for 12-inch naval guns. The ingot, weighing 42 tons, having been reduced by 28 per cent. at the top and 4 per cent. at the bottom, is perforated in the lathe with a 9½-inch hole, which is subsequently enlarged in three heats by a series of conical punches driven through by a 25-ton steam-hammer, and subsequently forged down on a mandrel to the length, about 20 feet, required for finishing. In this manner perfectly sound tubes can be obtained from an ingot of 40 tons, instead of one of 65 tons, formerly required. Another novelty in these works, shown in a model, is the arrangement of the open-hearth furnaces and the large hammer, which are put in one line, so that the same overhead electric crane serves both for casting and forge purposes. This has been at work with complete success since 1893.

The Chatillon, Commentry, and Neuve-Maisons Forge Company occupy a position comparable to that of Saint-Chamond in the central octagon hall, with a large and varied collection of products, ranging from armoured forts to printed tin plates and wire. Among the most notable objects are several examples of gun towers for land fortresses with mushroom roofs, both in malleable and cast iron, which are partly sectioned to show the depth of chill; one of the columns of a new forging press, 40 feet 4 inches long and 20¾ diameter, weighing nearly 21 tons, and some of the patterns of the cast steel arched ribs of the Alexander III. bridge.

The Commentry, Fourchambault, and Decazeville Company, one of the largest producers of coal and iron in Central France, send a very full series of products illustrating their operations, including coke and by-products made in Otto and Coppée ovens, cast iron from alluvial and oolitic ores, and basic steel ingots and forgings in various stages of manufacture. A more special interest attaches to the steels with high percentages of nickel produced at the Imphy Steelworks, which have been described in an important memoir by Mr. Guillaume, published a short time ago. These by special heat treatment can be made to vary in physical properties in a very remarkable manner, being made magnetic or non-magnetic at will, and their dilatation by heating can be similarily varied. The latter property has been applied to the production of wire having the same co-efficient of expansion as glass, and therefore capable of replacing platinum in the manufacture of incandescent electric lamps. Another alloy with 35 per cent. of nickel is practically non-dilatable at ordinary temperatures, the co-efficient of extension being only 1/500,000 per degree Centigrade. This has been applied to the construction of pendulums for observatory clocks and standard bars for geodetic purposes. These products are also exhibited in the Military Pavilion, where they can be more readily examined, the light being better than in the main building.

The Société des Acieries de France, having its principal works at Isbergues, near Bethune, produces both Bessemer and open-hearth steel from Spanish, Algerian, Elban, Greek and other high-class ores, imported through Calais and Dunkirk, which are smelted with coke made from local coal, with some occasional supply from England, the pig irons melted being of the highest quality, with a maximum of 0·05 phosphorus and 1·25 to 1·90 manganese. The products are very largely rails, among which some heavy flanged forms for tramways weighing up to 105 lbs. per yard, with a groove in the head 1⅝ inches deep, and very thin web and flange are noticeable as examples of difficult sections. And more remarkable is the new fish-plate joints for chair-rails adopted by the Western Railway of France. These are about 5 feet long, the principal plate, which has a foot about 8 inches broad, weighing 127 lbs. to the yard, is of an irregular form, which was specially difficult to roll with cast iron rolls, and when many of these had been broken, cast steel finishing rolls, one of which, weighing 6½ tons, is exhibited, were substituted. With these 400 tons of these plates have been successfully rolled. This joint has been adopted in the Exhibition lines from Courcelles to the Champ de Mars, and is also shown in the Western Company's exhibit at Vincennes. Another fine object is a cast steel rolling-mill pinion, weighing 4½ tons, of the same steel as the mill rolls. Another example of mill machinery is the Banning mill, a combination of two pairs of two-high rolls, in which all the grooves for the sections that the mill is capable of producing are concentrated in a very short length of rolls without any waste grooves. With this mill 120 tons of ¾ round steel bars have been rolled in twenty-four hours.

The same Company have works at Grenelle and Javel in Paris, a short distance below the Exhibition, on the left bank of the Seine. The first of these was originally founded for the conversion of old iron rails into joists and other builders' ironwork, but with the exhaustion of the rail supply, open-hearth furnaces to work with town scrap have been substituted in a new works at Javel, which has recently been started. In connection with these an electric charging machine, of which a model is shown in the Exhibition, has been adopted. It is of a comparatively simple form, and intended to work radially, so as to supply furnaces placed opposite to each other.

The Denain and Anzin Blast-Furnaces, Forges, and Steelworks Company send a very large and varied collection of products, made both by basic and acid methods, the ores smelted being drawn from a very wide area, including Lorraine, Spain, Sweden, and Greece for iron, and India for manganese, about 200,000 tons of pig iron being produced annually. A notable feature in the exhibit is a fine block of rubio ore weighing 4½ tons. Among the cast iron specimens is a *Fonte Speciale* having a tensile strength of 92·2 kilos., with 2 per cent. elongation, which can be forged. As examples of the plates shown may be mentioned one measuring 57 feet by 8 feet 2 inches and ½ inch thick, and a boiler end 10 feet 2 inches diameter and 0·72 inch thick. The tensile strength of the latter is 24 tons with an elongation of 32 per cent. on 8 inches. An object calling for special mention is the case in the centre of the court, which contains tested samples of steels alloyed with variable proportions of chromium, nickel, manganese, and silicon, with details of their tensile strength, elongation, &c. This collection, which is a very full one, is partially duplicated in the same Company's exhibit in the Naval and Military Pavilion.

One of the most effective displays in Class 64 is that made by the Forges de Douai, whose exhibit, consisting largely of pressed work, such as furnace plates, steam domes, manhole covers, and other boiler fittings, shafts and cranks for marine engines and locomotive wheels, arranged as a tall arch, formed a fitting entrance to the Metallurgical Section from the main door of the Palais.

The Escaut and Meuse Company of Anzin and Val Benoit, near Liége, exhibit many large examples of tubes, both solid drawn and welded. The former are made from solid ingots by the Mannesmann and Robertson processes, and the latter both by butt and lap welding. Among these are a rolled strip 7 inches wide, 0·12 inch thick, and 213 feet long; another of 19·7 inches wide, 0·2 inch thick, and 151 feet long; lap welded tubes 13·8 inches diameter and 20 feet long; a brine circulating tube for the Poetsch freezing process; perforated and cupped ingots from 5 to 90 feet, made by one passage of the hydraulic press, and a weldless tube 4 inches in diameter, 0·14 inch thick, and 56 feet long rolled into a spiral. The gas-welded work includes a main steam-pipe 46 feet long, 34·6 inches in diameter, with several flanged nozzles; a steam diver of 39·2 inches diameter 17 feet high; a section of a sailing ship's mast, and a reservoir for compressed air at 1500 lbs. pressure, 10·8 feet long, 19·7 inches diameter, and 1 inch thick, with ends and connecting boss welded on.

The ironworks of the Meurthe and Moselle region have a prominent representative in the Blast-Furnace, Forge, and Steelworks Company of Pompey, near Nancy. In 1889 this Company made a remarkable display of ironwork as applied to architectural design, besides furnishing a large part of the buildings and the whole of the iron for the tower of 300 metres, and on the present occasion it has applied the higher geometry to decorative purposes by constructing a surface of the second order—a hyperbolic paraboloid—as a trophy, in which the ruled lines defining the surface are made of bars, rails, angles, and other sections in steel, the geometric axes being represented by an inclined and a vertical frame made of plates and joists, the latter being crowned by an open framework studded with polished railway buffers, forming a sphere of seven feet in diameter at a height of 65 feet from the floor. Within and around this remarkable structure numerous specimens are arranged illustrating the raw materials employed and the quality of the finished products, which are entirely made from oolitic ore by the basic method, both in the converter and the open-hearth furnace, the total weight of the objects exhibited exceeding a hundred tons. The steel castings include several Simons wheels and a Bessemer converter rack-and-pinion with helical teeth. The numerous tensile and working tests are arranged upon a table weighing 3 tons, made of chequered steel plates, which is supported by a serpentine foot formed of a steel flat 302 feet long with 80 bends. Another specimen of cold bending and hammering is a ½-inch plate 50 inches broad and 66 feet long, rolled into a spiral tube about 20 inches diameter. The sections rolled in the bar mills, amounting to 550, are shown in a glazed cabinet. Many of these are of an unusual kind, which were originally designed for the Eiffel Tower. The works, founded in 1871 with two blast-furnaces of 100 tons capacity, have now been increased by two others of 200 tons each, giving a total make of 600 tons daily. The steel-making plant includes three 10-ton converters and six 14-ton open-hearth furnaces. A considerable proportion of the blast-furnace slag is utilised, yielding 30,000 tons of cement and 6,000,000 of brick per annum. Axles and other railway supplies are made at a separate forge and foundry at Apremont in the Ardennes, and a portion of the coke supply is obtained from Seraing in Belgium, where the Company owns a battery of 92 ovens.

The blast-furnaces and foundries of Pont-à-Mousson, the most prominent representatives of pipe-founding in the Exhibition, contribute a large collection of pipes of all kinds for gas, water, and drainage purposes, a special feature being the Rogé method of strengthening cast iron pipes by steel hoops put on hot. This has been applied to a 39-inch main nearly 5 miles long, between the Rhone and a high-service reservoir at Lyons, and to others of 49 and 60 inches as syphons about 3½ miles long in the new aqueduct bringing the spring water of Loing and Luinain to Paris. Nearly 20,000 tons of these pipes have been made in the past three years. The works, situated a few miles north of Nancy, include five blast-furnaces, making about 300 tons of foundry iron daily, which is almost entirely converted into pipes, a considerable portion being cast direct from the blast-furnace. From 3¾ to 4½ miles in length of pipes are produced in the foundry per working day, all being cast upright, and tested by hydraulic pressure of 15 to 25 atmospheres. This exhibit also contains a model of the shaft at Arboué now being made by the Poetsch freezing process to the grey bed of ore at 140 metres deep. This is 16½ feet diameter, requiring about 1000 tons of cast iron tubbing, and will be equipped for an output of 2000 tons daily, with pumping power capable of raising 23 tons of water per minute.

The Société Métallurgique de Gorcy, makers of pit tubbing for collieries and other mines, have arrayed a complete ring of tubbing, 23 feet in diameter, as an arch over one of the main passages. Associated with this are the valves and burners of a Cowper stove, in which some new features are introduced.

Another excellent display of pipes is made by the Fumel Works of the Metallurgical Society of Périgord. It adjoins that of the Pont-à-Mousson Works.

The Micheville Steelworks Company, of Micheville Villerupt, have, as a principal feature of their exhibit, a tall trophy built up of curved and straight joists, somewhat resembling a church steeple. All the ores used and the intermediate products are very fully illustrated with analytical and other details. This is one of the best exhibits for study for any one wishing to obtain a general knowledge of the conditions of minette smelting quickly.

The Longwy Steelworks Company of Mont Saint-Martin send some large and heavy steel castings, including a plate roll partially finished from the ingot, a large pinion, and a considerable number of bars and sections. Among them is an extra hard steel rail of 56½ tons tensile strength, with 18 per cent. elongation, which supported 92 tons when laid on bearings 39 inches apart, and bore an impact test of 6 cwts. falling 20 feet without breaking.

The character of the pig iron made in Lorraine is most completely exemplified in the collection shown by the Comptoir Métallurgique de Longwy. This includes a series, classified according to numbers and uses, of foundry steel-making and forge pigs, cement, bricks, paving slabs, and other slag products, pictures of ore workings, views of smelting works, and a model of a mineral-carrying barge for the Chiers River Navigation, now in course of completion, and which is expected to carry a million tons per annum as a minimum.

The Marseilles Blast Furnaces at Saint-Louis, Marseilles, which, under the management of the late lamented Professor S. Jordan, have contributed so much to the development of high manganiferous metal smelting, send a collection of their products, including foundry and forge pig iron spiegel with 10 to 20 per cent., ferro-manganese with 80 to 87 per cent. of manganese, ferro-silicon with 10 to 17 per cent. silicon and 1 to 3 per cent. manganese, silicon-spiegel with 10 to 14 per cent. silicon and 16 to 20 per cent. manganese, and ferro-chrome with 20 to 60 per cent. of chromium. This, although small, is an exceedingly interesting exhibit and one meriting careful inspection.

The Brousseval Foundry Company is one of the principal representatives of works producing strong foundry irons from alluvial ores, which are used for pipes, gas retort fittings, lamps, machinery, and ornamental work, all of which uses are fully illustrated in Classes 64, 74, and 87, as well as in the gas and electric light standards in the gardens of the Exhibition. Two notable examples shown in Class 64 are a cast iron melting pot weighing 9⅛ tons, and a double-bottomed casting with 50 tapered projecting nozzles on either side, 10·6 feet diameter, weighing 4·7 tons. These are for chemical manufacturers' use.

A smaller collection of the same kind is supplied by Messrs. E. Capitain-Geny & Co., of Bussy and Joinville, Haute Marne. The metal, smelted with charcoal from the concretionary brown ores of Champagne, is cast from the blast-furnace direct. A notable object is a cylinder casting for the large express engines of the North of France Railway.

The larger ornamental castings of the works in this group, including the Val d'Osne, Durenne, and other celebrated foundries, producing statuary, &c., are exhibited in the Ornamental Arts building.

Steel castings made from the converter are contributed by Messrs. G. Robert & Co., Messrs. Hachette & Driout of Saint-Dizier, who make converter castings up to 3 tons weight in malleable and weldable metal, and the Meuse Steelworks of

Stenay. The latter Company exhibits the model of a small converter with side tuyeres and a pocket in the neck to facilitate pouring when casting direct.

The Saut-du-Tarn Steelworks contribute an excellent collection of tools, scythes, files, and other articles, both in puddled and cast steel, made from the manganiferous, spathic, and brown ores of the Pyrenees. The works, situated at Saint-Juery, near Albi, have a disposable fall of water of about 2500 horse-power. The principal ore supply is derived from a mine about twelve miles distant, and coal and coke for smelting are drawn from the coalfields of Albi and Carnaux, which are close at hand. The crucible steel is melted in seven gas-furnaces; that for scythes and agricultural implements is mostly puddled.

Another large exhibit of steel goods for agricultural purposes is supplied by Messrs. Gouvy & Co. of Dieulouard, Meurthe-et-Moselle, including shovels, forks, plough fittings, cart tires, &c. The materials used are natural (puddled) and refined shear steel from the puddled blooms.

The principal French representatives of tin-plate manufacture are the Société de Cirages Francais, owners of the well-known forges of Hennebout in Brittany, where tin-plate for the sardine packing trade is largely produced, and the Montataire Forge and Foundry Company, who have blast-furnaces and steelworks at Frouard, Lorraine, open-hearth steelworks, rolling-mills, turning and galvanising works at Montataire, about 30 miles north of Paris, and tin-plate printing and ornamenting works at Nantes, the position of the latter being also determined by the requirements of the packing trade. Montataire is of interest historically, as having been the first place in France where tin-plate was made in 1813, as well as the site of Sudré's experiments on the smelting of steel in large masses without crucibles, made in 1862, shortly before the problem was solved by the application of the Siemens furnace to the purpose by Messrs. Martin of Sireuil.

The subject of plant for iron steelworks is principally illustrated by Messrs. A. Delattre & Co. of Ferrière la Grande, Maubeuge, who have sent the roughing pair of a reversing joist or rail-mill, with 33½ inch rolls, and hydraulic rack-and-pinion gear for the setting screws, the whole being complete with the exception of the roll counterbalancing gear. This represents a class of mill that has been supplied to several large steelworks, including Denain and Anzin, Vezin Aulnoye, and Saint-Chamond, and it is supplemented by an excellent series of photographs and a descriptive pamphlet containing details of the arrangement of large basic steelworks plants carried out by the firm. They also show a special machine for cutting test-pieces out of plates and flat bars at the rate of ten per hour from material 0·4 inch thick.

Furnace construction is further illustrated in the form of drawings, which are arranged upon a screen in the French gallery adjoining the retrospective museum. These include views of several new blast-furnaces erected by Messrs. Charles Munier's Sons, a modification of the Whitwell stove by Mr. C. de Mocomble, and some new applications of the Lencauchez gas-producer and furnace to steel and copper smelting, and zinc reduction by Messrs. Toisel, Fradet, Lencauchez, & Co. The series is completed by several examples of blowing blast-furnace and Bessemer and rolling-mill engines by the Société Alsacienne de Construction Mécanique. This collection, although in a somewhat out-of-the-way position, will well repay a careful examination by those having time for the purpose.

The newer alloys for steelmakers' use containing rare and refractory metals are represented in the gallery of the main building by a small collection contributed by Messrs. A. Monin & Co., of Grigny, Rhone, containing ferro-chromium up to 65 per cent. chromium, ferro-silicon up to 52 per cent. silicon, and ferro-molybdenum with 50 per cent. of molybdenum, together with the minerals from which they are produced. The most important illustrations of these rare metals are, however, to be found in the collection exhibited by Mr. Moissan in the special electric pavilion adjoining the La Bourdonnais boiler-house, which no member should if possible omit to visit.

A few references to the exhibits of aluminium and nickel, metals of interest to the iron-smelter, may be admissible. The Company known as "Le Nickel," smelting the New Caledonian ores at Havre, Glasgow, Birmingham, and Iserlohn, has its principal exhibit in the Military and Naval Pavilion, where it shows a relief map of the Island of New Caledonia, samples of the ores and smelting products in nickel and cobalt, and a very large series of nickel steels made by most of the principal steelmakers in France, the details of these last being given at length in a descriptive pamphlet. Smaller exhibits of a similar character are also exhibited in the New Caledonian Pavilion, and that of the French Colonial Ministry on the Trocadero. Another exhibit covering some of the same ground is that of the "Ferro-Nickel" Company in the gallery of the main building. This contains, besides iron, nickel alloys which are considered to be preferable to pure nickel for steelmaking, German silver and other copper alloys, and the original samples of nickel steel exhibited in 1889, when they were received with comparative indifference.

The principal aluminium exhibit in the gallery of the main building is that of the French Electro-Metallurgical Society of Froges, Isère, having alumina works at Gardanne and electrolytic reduction works at Froges and La Praz, where the Hérault process is used under the direction of the inventor. At the latter works, where 15,000 horse-power is disposable, the power water is carried across a river by a rivetted steel pipe 7·9 feet in diameter, passing an arch of 213 feet span without intermediate supports or bracing. This includes pure aluminium and its alloys in ingots, bars, plates, and other rolled forms, castings, and a very full series of manufactured objects. In the special electrical pavilion will be found a series of thick plates and bars of aluminium of high purity by the Alais and Lamage Company, formerly Pechiney & Co., and in the same place an application of aluminium in the place of copper for conveying a heavy electric current is shown. There are some fine examples of aluminium and aluminium-bronze castings in the main building by Mr. M. Corbin, and also by Mr. H. Partin of Puteaux, so-called Partinum metal. Among the latter are frames for 50 and 35 horse-power motors for the heavy automobile carriages or "*tracteurs*" of Messrs. De Dion Bouton & Co.

Another interesting application of aluminium shown outside the Military Pavilion on the Quai d'Orsay is a portable military bridge made for the Aluminum Commission by the Forges de Sedan from the designs of General Dumont. This is a lattice truss girder for a span of 57 feet, with three beams each in two pieces, with a total weight of 18 cwts. for the metal work and 12 cwts. for the wooden platform. This, when tested with a load of 9 tons, gave a temporary deflection of 2¾ inches, and a permanent set of 0·9 inch, and was equal to carrying a 46-cwt. military waggon with 6 horses and 40 men passing at the double.

The independent exhibit of Messrs. Schneider & Company of Le Creusot contains such a large variety of objects that it will be impossible to notice more than those representing the earlier stages of their manufacture, leaving the consideration of finished machinery, locomotives, marine engines, &c., as beyond the scope of this survey. Among the most prominent of these are the full-size model of the 150-ton nickel steel ingot for a large forging, and that of the finishing rolls of the armour-plate mill, represented with a 60-ton ingot under treatment; and among the large steel castings, the cylinder and jacket of a press for fluid steel compression of 20 or 25 tons weight, a piston for the 100-ton steam-hammer, and a fluid compressed ingot of 28 tons. Among the forgings may be noticed a rough hollow block for a 12-inch gun of 18·15 tons, and a finished hollow shaft for a battleship, forged on a mandrel 76·8 feet long, weight 36½ tons. In addition to a historical series of tested armour-plates showing the continued increase in their resistance to penetration, two examples of unfinished plates as taken from the mill are shown, one being 55·8 feet long, 6·9 feet broad, 3·9½ inches thick, and 28 tons weight, and the other 50·5 feet long, 4·9 feet broad, 7·87 inches thick, and 33 tons weight. In connection with the large express locomotive which forms such a prominent object in the collection, a series of tests of the steel used in its construction deserves attention.

In the exhibits of foreign countries, the separation of the three classes in the Metallurgical Group has not been observed to any great extent, so that it becomes difficult in a rapid survey of their contents to avoid noticing objects which have not found their place in the French Section, and for this reason the following notices are of a less systematic character than the preceding ones. The arrangement followed is that of the distribution of the space in the building, beginning on the eastern or left-hand side of the main building.

Italy.—The principal feature in the Italian Section is the large exhibit of the Terni Steelworks Company, which occupies the larger part of the ground-floor space. In this are included a model of their principal establishment, the well-known water-power steelworks and forges at Terni, described in Sir B. Samuelson's paper in the Journal of the Institute (1887, No. I.), numerous examples of heavy castings for waterworks, pipes from 0·8 to 60 inches diameter, and sluice valves of 7½ and 9½ tons, rails and fish-plates, the cylinder covers for the engines of a large cruiser in cast steel, projectiles of all sizes up to 13·6 inches diameter, and armour-plates. The latter are of two kinds, called respectively "Terni Patent" and "Terni Special," the first being made to resist penetration without special regard to immunity from cracking, while the second, being of a more ductile character, may be penetrated at extreme velocities, but develop no surface fractures. Four specimens of each class of plate, ranging in thickness from about 3 to 6 inches, are shown with the details of penetration, velocity, &c., of the different shots marked on them, these details being further presented in a descriptive pamphlet. The pig iron used at these works is partly derived from blast-furnaces in the Val Trompia; the fuel is lignite from mines at Spoleto. Some fine examples of fossil tree trunks from these mines are exhibited, together with numerous photographs of the works. Another collection of steel castings made in the Roberts converter is contributed by the Milanese Steel Foundry Company of Milan. This contains models in steel of stem and stern-post castings executed for the Italian and other navies, the full-sized foundry patterns being shown in the Naval Pavilion. Mr. Frank Griffin of Brescia sends examples of the strong foundry iron of that district, including a large plate roll and railway or tramway wheels cast in chill.

The gallery of the Italian Section contains a fine case of aluminium goods by Mr. Claudio Zecchini of Milan, and a very complete collection illustrating the geology and mineral resources of the kingdom, made by the Royal Corps of Mining Engineers. In this the iron ores of Italy are well displayed by a series of about a hundred specimens from Elba, the Alpine and Sub-Alpine regions, Naples, and Sicily.

Luxemburg.—The metallurgical industry of Luxemburg, which is essentially of the same character as that of Lorraine, is most prominently represented by the Dudelange Blast-Furnace and Forge Company, who occupy the centre of the court with a trophy about twenty feet square and nearly double that height, built up of ingots, billets, bars, and finished products, the effect being heightened by ornamental lines produced with polished rail and sleeper sections, and by four well-modelled figures, namely, a miner, a blast-furnace keeper, a puddler, and a fitter, typical of the principal branches of the iron industry. The works, which have a productive capacity of 250,000 tons, are represented in a large number of views and drawings, and a section of the newest blast-furnace is given, which is perhaps the best representation of modern Continental furnace construction in the whole Exhibition. The direct use of blast-furnace gas for power is also used on a large scale and illustrated by the plan of the new electric power station intended to contain two groups of gas-motors of 1000 and two of 500 horse-power each.

The details of the occurrence and distribution of Luxemburg ores are very completely given by the other exhibitor in the court, the Lorraine-Luxemburg Syndicate for the sale of pig iron. This collection includes large-scale geological maps and sections of the Differdange, Esch, Rumelange, and Dudelange iron ore districts, and a very full series of samples of the standard classification adopted for pig iron, including foundry numbers 1 to 5. Extra silicon with 5½ to 6½ per cent. silicon, two classes of basic iron marked OM without manganese, and MM with 1·25 to 2·0 per cent. of manganese, and forge iron, grey, mottled, and white. The total ore production of this small country was 5,995,408 tons in 1899.

Germany.—The German Section of Group XI. contains little, if anything, bearing on the production of iron and steel, the strong part of the display being in mining and metallurgical machinery, the most prominent object, placed in the centre of the ground-floor, being a three-cylinder reversing rolling-mill engine, constructed for the Imperial Japanese Steelworks at Yawatamara by Messrs. Ehrhardt & Scheiner of Schleifmuhle, Saarbrücke. This, with steam at 150 lbs. pressure, is intended to develop 5000 horse-power when running at 160 revolutions per minute. Adjoining this, on the south side, is a 1200-ton direct acting steam and hydraulic press of the well-known form made by Messrs. Breuer, Schuhmacher, & Co. of Kalk, with a hydraulic bar shear of a very compact form, the pressure pumps being driven by an electro-motor attached to the framing, by the same makers. A fine piece of flanging, a boiler front with two holes for furnace tubes, and a boss for the water-gauge attachment produced at one heat, is shown in illustration of the work done by the press. Other machines for flanging and deep stamping are shown by Mr. L. Schuler of Goppingen and Mr. R. Chillingworth of Nürnberg, the latter making a special exhibit of driving pulleys, either solid or built up in two or more segments, stamped out of steel-plate, which are being largely used instead of cast iron or wooden wheels. The northern side of the court is occupied by the Allgemeine Electricitäts Gesellschaft with a Riedler "express" pump driven by an electro-motor of 75 horse-power, intended to lift 240 gallons per second to a height of 900 feet, the space occupied for this combination being only about one-fourth of that required by an underground steam-pump of the same capacity. Adjoining this is a large show of electric-driven rock-drills, both of rotatory and percussive kinds, by Messrs. Siemens & Halske.

The gallery of the German Section is largely devoted to amber, but also contains several objects of great metallurgical interest, the most notable being that of the Thermo-Chemical Industry Company of Essen, illustrating Dr. H. Goldschmidt's method of reducing the oxides of chromium, nickel, manganese, and other refractory metals by combustion with finely divided aluminium, when, as a consequence of the intense local development of heat, the reduced metal, although free from carbon, melted, as also the slag, the latter being pure alumina, which is tinted with a little chromium oxide, and crystallises in the form of corundum or ruby. This being harder than natural emery, has found an application as an abrasive material under the name of "corubin." Another application of this method is to the welding of tubes or rails by the heat developed in the reduction of a mixture of oxide of iron aluminium and other substances, supplied as a mixture called "thermite," which is burned in a box surrounding the parts to be joined. Chromium and manganese of high purity are obtained by this method with great ease, and singularly enough the latter metal, which as high ferro-manganese is readily oxidisable, seems to keep perfectly bright in the air when free from carbon. A notable advance in the knowledge of working aluminium is shown in the exhibit of Mr. W. C. Heræus of Hanau, who has discovered that within a small range of temperature, nearly but not quite at a red heat, the metal may be welded, and several examples, including tubes, funnels, and the worm of a still, are shown in illustration of the method.

The Silesian Nickel Works show specimens of nickel smelted from pimelite and schuchardite These are indefinite hydrated silicates, somewhat like the noumeite of New Caledonia, with magnesia, alumina, and nickel oxide as bases. The maximum amount of nickel contained is 14 per cent.

One of the largest examples of welded work in the Exhibition is the gas reservoir sent by Mr. Julius Pintsch, made from steel plates supplied by the Borsig Works. This is a cylinder of 1766 cubic feet capacity, ½-inch plate, 59 inches in diameter, 65 feet 7½ inches long, with ¾-inch ends, welded by water-gas blowpipe flame, weighing 27,000 lbs. and tested to 284 lbs. per square inch. It is placed on the quay adjoining the Naval and Military building.

Great Britain.—The representation of the metallurgical industry of the United Kingdom is very small, being, so far as iron and steel are concerned, restricted to the West Riding of Yorkshire. The most prominent position is occupied by Messrs. William Jessop & Co., who send a varied collection of objects in cast steel, including wheels and pinions with straight and helical teeth, mine wheels, die blanks, sections of Swedish iron, blister and cast steel of different tempers, soft centre ingots and bars, ribbon steel for saws and pen steel, the make of the latter article being more than 1000 tons annually. Other Sheffield firms represented are Messrs. Seebohm & Dieckstahl, by a collection of sections and fractures of blister and cast steel in ingots and bars, in all the different conditions of manufacture; Messrs. Beardshaw & Son, showing a large collection of steel bars made to special sections for machine tool-cutters; Messrs. J. J. Saville & Co., crucible cast steel tools and files; and Messrs. J. H. Andrew & Co., cast steel hammers and small picks. Malleable iron is represented by the Farnley Iron Company, who contribute a small series of forge and other working tests to show the special qualities of best Yorkshire iron. They have also a large exhibit of enamelled fireclay goods in the ceramic department. Two interesting exhibits of a retrospective character in this section deserve notice. These are the case of specimens of the first products of the Bessemer process, presented to the Institute by Sir H. Bessemer, and exhibited by the Council, and specimens and records of the first experiments made by Mr. G. J. Snelus in dephosphorising iron, together with a series of statistical and other tables, showing the present output of the basic process, which has been developed from these experiments. Mr. B. H. Thwaite and the Blast-Furnace Power Syndicate exhibit a series of drawings and documents on gas-furnaces and the use of blast-furnace gas for internal combustion engines, with a sectional model of a new form of blowing engine for blast-furnaces.

The large exhibit of Messrs. Vickers, Sons, & Maxim, contained in a separate building on the Quai d'Orsay, is mostly devoted to artillery, including 6-inch, 7½-inch quick-firing guns, a 12-inch 50-ton gun, and field-guns and equipment of various sizes, while the gallery contains a series of models of the ships built at Barrow. Besides these there are tests of locomotive crank axles and a 9½-inch tyre, and plaster casts of special nickel steel, Harveyed and other armour-plates tested at Portsmouth, the heaviest being 10 inches thick.

A series of small but representative specimens of British iron ores will be found in the gallery, forming part of the collection of British minerals sent by the Home Office. The iron ores of the Canadian Dominion are fairly well represented in the collection of the Geological Survey Department, and there is an interesting exhibit of charcoal iron, made from bog iron by the Canadian Iron Furnace Company. These ores have been worked since the end of the 17th century, and produce a metal specially suited for chilled cast railway wheels. The iron industry of India is principally represented by pig iron castings and views of the Bengal Iron Company's works at Barrakur; but in addition to this there is a large collection of iron ores and products obtained by the native smelting methods, formed by the Geological Survey of India, the examples illustrating the production of highly carburised crucible steel (Wootz) being of special interest.

The British Aluminium Company makes a notable display of the products of their different establishments, both on the ground-floor and the gallery of the British Section. In the former are shown examples of cast and other objects in aluminium for large uses, including a still for aniline distillation, alloys both heavy and light, the former consisting mainly of aluminium hardened by the addition of foreign metals, such as copper, zinc, titanium, chromium, and tungsten, in proportions varying from 1 to 10 per cent., while the latter are the aluminium bronzes, or copper alloyed with 5 to 10 per cent. of aluminium, with, in some instances, a small amount of ferro-manganese. Special bronzes of this kind, with a tensile strength equal to that of mild steel, are now extensively used for small screw propellers. On the upper floor are placed smaller objects for domestic and ornamental use, and examples of insulated conductors for electrical purposes. The ornamental panels and vases made at the School of Art, Madras, are of great interest, as showing the suitability of the metal for use by Indian workers in brass and copper. The nickel mines of Sudbury, Ontario, which, together with New Caledonia, furnish nearly the entire supply of the world, are very well represented in the Canadian Mineral Department by a joint exhibit made by the Canadian Copper Company and the Port Orford Smelting Company of New York, the first representing the mining and concentration of the nickel and copper regulus, and the latter the separation and refining of the two metals.

Sweden.—The Swedish Section contains a remarkably well-arranged series of exhibits, contributed by some of the most famous works in the central and southern parts of the country, including among others, Österby, Avesta, Söderfors, Domnarfvet, Iggesund, Wikmanshytte, and Uddeholmen. These, as will be well known to most of the members, are makers of wrought iron for steel-converting purposes, as well as of cast steel of the highest class, and it will therefore be of little use to go into any very close individual description. The Stora Kopparberg Company of Domnarfvet shows a large series of finished products in mild and hard steel, as well as several of the famous charters and documents connected with the foundation of the Company, which were described in the Journal of the Institute on the occasion of the Swedish visit. Österby, the oldest of the Dannemora forges, shows sections of the pig iron used in the Walloon process, bars of the double bullet brand, and cast steel made from it. Walloon iron and its products are also contained in the Iggesund exhibit and that of Söderfors, these works being part proprietors of the Dannemora mines. The Fagersta collection, in addition to samples of products, contains makes of great general interest, including studies of structures due to hardening and converting by Mr. Brinell, who has succeeded in producing almost every kind of fracture in steel bars, including alternate stripes of coarse and fine grain, by varying the heat treatment; a method of determining the hardness of steel and other metals by measuring the diameter of the indent made in a plate by a hardened steel ball under a definite pressure; studies of the causes of blowholes in ingots, and a method of estimating the carbon in steel by the angle of fracture of the test-piece under the bending test. Some chrome steel is also shown, containing 1·35 per cent. chromium, made by the direct addition of chromic iron ore to the bath in the open-hearth furnace, 6·2 cwt. of ore being sufficient for the charge of 10 tons of steel.

Mr. C. W. Bildt of Stockholm sends his well-known automatic feeding arrangement for continuous and uniform supply and distribution of the fuel in gas-producers.

The iron ore regions of Lapland are represented by a geological map and some special plans of the mines of Gellivare, a model of Kiirunavaara and Luossovaara ore mountains, and specimens of the ores and rocks from these localities, all of which have been fully described in the Journal of the Institute. The amount of ore exported for Luleå in 1899 from Gellivare was 920,997. This collection is further illustrated by the excellent oil painting of Kiirunavaara under the rising (midnight) sun, which was a principal attraction at the Stockholm Mineral Exhibition in 1897. The Norbotten Mineral Improvement Company, owning the magnetic separating works at Luleå, show samples illustrating their process and the fertiliser (Wiborgh phosphate) made from the separated apatite, which contains

22·85 per cent. of total P_2O_5 and 21·34 per cent. soluble in nitric acid.

Russia.—The remarkable progress made in iron and steel manufacture in the Russian Empire since 1889 is very prominently shown by the large and handsome exhibits brought together from all parts of European Russia and the Ural, the whole being arranged in a more complete manner than those of other foreign countries. Speaking generally, the larger and heavier branches of manufacture are represented by the works in Poland, Central Russia, and the Donetz region, and the lighter and ornamental ones by the Ural works. Among the Polish works, that of Huta Bankowa, situated on the eastern extension of the Silesian coalfield, is interesting as having been the first makers of basic open-hearth steel, using liquid metal from the blast-furnace to the extent of 80 per cent., with addition of ore and a minimum of scrap, which has been practised since 1889, and eight out of eleven open-hearth furnaces are so worked at present. A full series of the products of the rolling-mills in plates and bars and castings in steel, together with tests of the materials, ore, and fuel, are shown.

The Sosnowitch forges and tube works of Warsaw make a remarkable display of their products, plates, strips for lap welding, and tubes, which are attractively displayed in a roofed building made up of tubes of different kinds. These are made from open-hearth steel using imported pig iron; but a blast-furnace is now nearly completed.

Lately a special plant for the production of coiled and spiral tubes in continuous lengths up to 350 or 400 feet has been laid down, and a specimen of the work is given in a pipe 1·5 inch inside and 1·9 inch outside diameter, 151 feet long, closely coiled into a spherical form.

The Hughesofska Jouzovo (Hughes) or New Russia Company's Works, the oldest and largest of those smelting the rich hæmatite ore of Krivoi-Rog, illustrate the operation in a very complete manner, a full series of samples of ores, fuel, fluxes, and products being contained in an ornamental building formed of joists and rails in the north-west corner of the court, but being under the gallery, it is rather badly lighted. As a test of the ductility of the rail steel, a piece is shown with one end worked up into a palm tree.

The Donetz Forges and Steelworks of Drouikovka send a somewhat similar collection to that last mentioned. This Company dates from 1891, and now has two blast-furnaces, making about 300 tons a day, three 8-ton acid Bessemer converters worked with liquid metal through a mixer of 100 tons, and two 20-ton basic open-hearth furnaces. The rail-mills are worked by a three-cylinder reversing engine of 3000 horse-power, and ingots of 42 cwts. are rolled up to 220 feet in length, giving five or six finished rails and joists, 12 inches high, up to 170 feet lengths. A similar engine drives the heavy plate and sheet mills, which are arranged on either side of it and worked alternately.

A combination of great interest is illustrated by the exhibit of the Ural Volga Company, who have lately established large steelworks and rolling-mills at Tsaritsin on the Volga, in connection with two groups of charcoal blast-furnaces at Lemeza and Aviziano Petrowski in the Southern Ural, the pig iron being carried in barges about 900 miles by the Bielaia, Kama, and Volga rivers to the steelworks, where the conversion is effected in basic open-hearth furnaces heated by naphtha residues (mazut) brought from Batum, a distance of 700 miles, by steamer on the Caspian Sea and the Volga. The barges carrying 500 to 650 tons of pig iron ore despatched from the works in a "caravan" during the summer freshet, when alone the upper part of the Bielaia River is navigable. The make of the two groups of furnaces, which draw their ore and fuel supplies from an area of about 2200 square miles, is about 2800 tons per month. The steelworks, which at present contain six 15-ton open-hearth furnaces and 14 plate, sheet, bar, and rod mills, are shown in a model as completed, the parts not yet erected being surrounded by a red line. In this two hot-blast furnaces to be erected at a future time are shown. The ultimate capacity is intended to be of about 120,000 tons of finished steel per annum. The engines in the rolling-mills, together of about 16,000 horse-power, are worked in connection with a Weiss central condenser placed in a shaft 50 feet deep, and discharging the condensed water through a walled gallery 400 feet long into the river. Three covered earthen reservoirs of a total capacity of 22,400 tons are provided for storing the liquid fuel. In addition to a very full series of products from the furnaces and steelworks, the most prominent object being a 60-lb. rail 256 feet long bent into eight loops, a large collection of views and drawings is sent, in which the construction of the oil-burning, smelting, and heating furnaces is shown in considerable detail.

The charcoal iron-making regions of the Eastern Ural find many representatives, one of the most important and attractive being the large exhibit from the mines and works of the Imperial domains in the Ural. This is of a very diversified character, being made up of contributions from the mines, forges, and furnaces of the Ural, the cutlery works of Zlatoust, and the Imperial arsenal at Perm. Among them are models of Caspian oil-tank and river steamers, and their engines, artillery, and projectiles, roofing and other thin sheets, and a remarkable series of ornamental castings. The Damascus, Khorassan, and other ornamental sword-blades and weapons from Zlatoust make a specially fine display, and a frame containing micro-photographs of steel fractures is specially noticeable.

Another great exhibit of ornamental cast iron work is that of Kytchtym, whose pavilion, placed in the gallery, rivals in attraction that of the Imperial works. This represents the products of an estate of 2200 square miles, of which about 80 per cent. is workable forest, supplying several small blast-furnaces and forges producing about 18,000 tons of bar or sheet iron, 2302 tons of small cooking stoves, cooking pots, &c., and nearly 200 tons of ornamental castings, the latter, made at the Kasli blast-furnaces and foundry, consisting largely of statuettes representing the bronze works of Kanaef, Lausar, Torokine, and other celebrated Russian sculptors, and arabesques and house-work for architectural purposes, which are well represented in the pavilion containing the collection. The thin pottery castings are also noticeable for their flexibility, some of the pots taking a certain amount of bending without damage.

Another excellent exhibit of pottery castings is that of the Toula furnaces in Central Russia. These are new works built to smelt brown hæmatite, which occurs in irregular masses on the carboniferous limestone on the railway from Moscow to Kursk.

The ore contains 0·8 to 0·9 per cent. phosphorus, and when smelted with hot blast (700 degrees Cent.) gives a metal which can be cast into pots 0·2 inch thick direct from the blast-furnace.

The works of Tagil and Louina on the Demidoff estates send a small but representative collection of products from the copper and iron works centring at Nischne Tagil, which, besides being attractive, has the merit of being excellently catalogued. The works, which were noticed in the Journal of the Institute, 1898, No. I., produce about 65,000 tons of finished iron and steel and 2000 tons of copper per annum. There are also large platinum workings on the estate, producing about 30 cwt. of crude platinum per annum from sands, and in connection with these the first find of platinum in the rock was made two years since.

Another large Ural estate, the Lysva domain of Count Schouvaloff, sends, among other products, some remarkable examples of thin polished sheet iron. The strong part of this exhibit, however, is from the platinum workings, which have been greatly extended of late years, and now supply about one-third of the whole annual produce of the world.

In addition to the samples shown by the different smelting-works, there are good illustrations of iron ores from Russian Poland, the Krivoi-Rog district, and the Ural, and of manganese ores from the Caucasus, in the collections from the Department of Mines and the Geological Survey department in the gallery. Other important Russian exhibits will be found in the Military and Naval Pavilion, including a collection of chains, tubes, and armour plates from the Admiralty works, Kolpino, and the steel-testing laboratory of the Obuchoff works.

Belgium.—The Belgian Section, like that of the German Empire, contains little relating to the manufacture of iron and steel, the principal representatives of these articles having confined their exhibits to small specimens and tests, which are collectively grouped in the gallery. The central feature on the ground-floor is supplied by a pair of horizontal blowing-engines for blast-furnace use, exhibited by the Société des Ateliers de Construction de la Meuse. These are of about 500 horse-power, and two similar engines have been supplied to the Toula blast-furnaces in Russia. The Andenne Clay and Firebrick Company make a large display of their wares, including blast-furnace hearth-bricks, stove fittings, and moulded pieces for gasworks and similar work in silica and alumina, for gaswork, coke-oven, and glass-tank furnaces, is shown by Mr. Camille Huroz. The Compagnie Générale des Conduites d'Eau de Liége send a series of sectioned waterworks pipes and fittings, with statistical details of work done in the water supply of foreign towns, more particularly in Chile and Japan. The rock-boring machines of Mr. J. François of Seraing are illustrated in different forms, including those for drilling shot-holes and the *bosseyeuse* for doing without explosives by drilling and wedging. Adjoining there is the Dulait rock-drill, one of the latest and most promising methods of applying electro-motors to drawing in mines, the motor, contained in a box on wheels, being connected with the drill by a flexible shaft. The iron and steel exhibits in the gallery form a collective exhibit from several representative works. Among them the Société Metallurgique de l'Espérance send a fine series of sections of railway, tram, and rack rails, chains, and sleepers, with tests of the material, and a fine drawing of the No. 4 blast-furnace at Ougrée, which is equipped with a double bell for gas saving, and a Jacob's ladder bucket elevator for automatic charging. In the same series will be found a large series of sections, principally of joists, contributed. by the Forges de la Providence, Marchienne-au-Pont; plates and large flats in steel from the Fabrique de Fer de Charleroi; a plate 32·6 feet by 6·5 feet wide and 0·5 inch thick, with good photographs of rolling-mills, &c., from the Forges de Clabecq; a remarkably good series of fractures of fibrous iron from Messrs. V. Demerbe & Co., Jemappes, and weldless tubes rolled from solid ingots by the Usine de Lembecq-lez-Hal. Some models illustrating a new application of blast-furnace slag to mining works is shown in the collective Belgian coal exhibit in the gallery by the John Cockerill Company. These include the lining walls of a shaft and an underground pumping engine-house, and a dam in a level, the material used being concrete made of broken slag and slag cement, which for such uses is found to be considerably stronger and cheaper than brickwork. A full description of these applications has lately been published by Mr. M. Habets. The more important exhibit of the Cockerill Company, the large blowing-engine driven by blast-furnace is, however, not included in this group, but is placed with the machinery in motion. It was described in the *Journal*, 1900, No. I., p. 109, and develops 700 horse-power with blast-furnace gas and 1000 horse-power with illuminating gas.

United States of America.—In this section the largest producing establishments are scantily represented, the Carnegie Steel Company only sending a set of blue prints of one of their large blast-furnaces, and the Illinois Steel Company a sectional model of a furnace and a collection of small-sized products, mostly tests. The most prominent position is occupied by the Colorado Fuel and Iron Company, whose works at Pueblo, Colorado, smelt the magnetic and hæmatite ores of Utah with coke from New Mexico and other mountain States. It is a comparatively new establishment, but has developed rapidly, and now produces 1½ million tons of coal, 950,000 tons of coke, 900,000 tons of iron ore, and 200,000 tons of finished steel, which, when the further extensions now in progress are completed, will be increased to 550,000 tons. The samples exhibited consist principally of rails and fish-plates, which are accompanied by a large series of maps and views of the different works and mines. The American Tinplate Company make a very full display of tin and terne plates of all kinds, together with the boxes used, and statistics of the work included in the construction and of the production.

The Crescent Steel Company of Pittsburg have a remarkably fine exhibit of crucible and open-hearth steel, and, following their practice at Chicago, they have illustrated the quality of their manufacture by examples of dies, drills, and other cutting tools made from their steel borrowed from other manufacturers, which are shown with statements of the work done by each article. The melting is done in Siemens gas-furnaces, the largest of 10 holes having a capacity for 60 pots, melting on an average 100 lbs. in a heat each, the total output of six heats in twenty-four hours being 18 tons, which is the largest yield obtained as yet from a single steel melting furnace.

Very fine displays of wire are made by the American Wire Company, who also show draw-plates and dies of all kinds, and by Messrs. John A. Roebling's Sons & Company, who send full-sized pieces of the East River bridge cable, and a model of the bridge.

Cast steel shells on the Hadfield system are sent by the Taylor Iron and Steel Company, New York, and forged projectiles with a guaranteed perforating power of one inch in addition to the calibre, by Berger, Illingworth, & Co., Newark, New Jersey.

The manufacture of foundry-iron and the classification of the products is very well shown in a remarkably good exhibit by Messrs. Rogers, Brown, & Co. of New York. The most interesting novelty, however, in the American Section is a new method of treatment of steel cutting tools invented by Messrs. Taylor & White, which, in turning nickel steel for guns, armour, shafting, &c., the average depth of cut can be increased from 0·23 inch to 0·30 inch, the average feed from 0·07 inch to 0·087 inch, and the average cutting speed from 9 to 25 feet per minute, or the weight removed per hour is increased from 31·18 lbs. to 137·3 lbs., or a gain in actual work of 340 per cent. This is shown in action by the Bethlehem Steel Company in the United States machine tool building at Vincennes.

Austria-Hungary.—The Austrian department, although small as regards number of exhibitors, contains very important contributions. Prominent among these is the exhibit of cast steel from the Kapfenberg Works of Messrs. Bohler Brothers, which contains examples of crucible cast steel in ingots and finished bars of all kinds, many of them, notably the ingot fractures, being of considerable size. The base of the manufacture seems to be largely natural steel made in the open fire and puddling furnace which is melted in clay crucibles. An interesting series of examples of crucibles with their charges, taken from the smelting furnaces at intervals of an hour, showing the progress of the smelting and the transition from a porous to a sound texture in the finished metal is placed in one of the lower cases near the floor.

The large exhibit of the Skoda Steelworks at Pilsen, Bohemia, is perhaps the most important of its class in the Exhibition. The principal object is the stern frame, rudder-post, and outer shaft brackets for a transatlantic steamer of 24,000 tons, together weighing 80 tons; a four-blade screw 12 feet in diameter; the bed-plate of a marine engine, weighing 11½ tons; a magnet ring 14½ feet in diameter, and several large pinions for turbines and other transmissions. A series of photographs hung round the walls of the court are of great interest, as showing the way in which these heavy and unwieldy objects are arranged for railway transit.

Mr. C. Später sends a large collection of products of the magnesite works at Veitsch, in Styria, including bricks of all kinds, converter bottoms, and a section showing the construction of a magnesia bottom in an open-hearth furnace, together with full descriptive catalogues in several languages.

The cutlery and scythe industry of the Austrian Alpine regions is represented in collective exhibits from Steyr, the Scythe and Sickle Makers' Union, and other manufacturers—which, however, are somewhat beyond the scope of the present paper.

The Hungarian department is very tastefully arranged, a group of miners at work being placed on one side, and another of smelters tapping a blast-furnace on the other. The principal exhibitor on the metallurgical side is the State works, having eight different establishments in several parts of the country, the most important those at Diosgyor and Buda-Pest in the central districts. In these about 120,000 tons of pig iron are made annually in two coke and six charcoal blast-furnaces, which is converted into wrought iron castings and steel bars and plate, as well as machinery, locomotives, and agricultural implements. Next in importance comes the Rimamurany and Salgo Tarjarn Company, making 1,000,000 tons of pig iron, which is nearly all converted into malleable iron and steel; and the Austro-Hungarian State Railway Company with five blast-furnaces, three at Reschitza and two at Anina, three Bessemer converters and four Siemens-Martin furnaces, making 60,000 tons of pig iron, 30,000 tons of steel, 40,000 tons of rolled bars and plates, and 15,000 tons of pottery castings, nails, tools, and railway materials. Messrs. Ganz & Co. of Buda-Pest are also considerable producers, but their principal exhibits are in the departments of machinery and railway plant. These and several smaller works make considerable displays of other products, which, however, are not of a kind calling for any special description. The most prominent object in this section is a group of the chains made at Diosgyor for the Eskutser Bridge over the Danube at Buda-Pest. The links of this are, eye bars 48 feet long, 1 inch thick, and 2 feet maximum breadth across the bolt-holes, weighing 31 cwt., which have been machined from rectangular flat bars and drilled out in groups on a plant specially designed for the purpose. By way of contrast, one of the links of the suspension bridge built by the late Mr. Tierney Clarke in 1847–49 has been placed above them. These, together with a stockless Tyzack naval anchor, are placed in the open arcade facing the gardens on the west side of the building.

Bosnia-Herzegovina.—Iron mining and smelting have made very considerable progress in Bosnia since the Austrian occupation of the country in 1878. Before that date the industry, although one dating from remote antiquity, was confined to the production of malleable iron from the ore in the majdan, or high-bloomery furnace, where it survived longer than in any other country in Europe, and even now is not completely extinct. Within the last few years, however, iron ore mining has been developed upon a scale of considerable magnitude, the most important workings being at Vares, near Serajevo, where a series of alternating beds of spathic iron ore and hæmatite, considered to be altered limestones of triassic age, and varying between 200 and 300 feet in breadth, are quarried for the supply of blast-furnaces at Vares and a malleable iron and steel works at Zenica. The present output is about 130,000 tons per annum, about two-thirds of it is smelted locally, and the remainder exported partly to works in Hungary and partly to blast-furnaces at Trieste, through the harbour of Metkowich, in Dalmatia. The amount of ore available for removal without subterranean working is estimated at 10,000,000 tons, the yield ranging from 46 to 65 per cent. There are two blast-furnaces, the newer one built in 1899, 69 feet high, and of 6200 cubic feet capacity, making from 80 to 100 tons of pig iron daily, from 53 per cent. ore upon a consumption of 17 cwt. of charcoal per ton, which is probably the largest make ever obtained from a charcoal blast-furnace in Europe. The product is about one-fourth grey foundry, and three-fourths white forge and steel-making pig, which is for the most part converted into malleable iron at Zenica; but a short time since a cargo was exported to Western Germany *via* the Adriatic and Rotterdam. These mines and works and their products are fully illustrated by a collection of samples and views placed on the basement floor of the Bosnian pavilion in the Rue des Nations, and they have been well described in a Memoir by Oberbergrath Poech, who has been intimately connected with their development, presented to the Mining and Metallurgical Congress in June 1900.

Spain and Portugal.—The contributions from these countries, which are mostly minerals, including iron, manganese, and copper ores, are placed in the south-west angle of the gallery, the main building adjoining each other, but in addition to these there is a very fine collection of samples of Biscayan ores, with a map and numerous views of the mines exhibited by the Circulo Minero de Bilbao, placed in the open arcade on the garden side adjoining the Buda-Pest bridge chain. In the gallery is a fine relief model of the Sommorostro mines (Franco-Belgian Company's). Spanish iron metallurgy is represented by the Campania de Asturias of La Felguera in Leon, who send a series of pipes, cast steel wheels, perforated steel sheets for coal screens, and a large and highly ornamental bronze bell, by the Fabrica de Miéres in the same province. The latter Company works a large group of collieries, producing 285,000 tons of coal annually, and two groups of blast-furnaces and forges making wrought iron and steel from local siliceous ores with some admixture of softer minerals from Bilbao. There are also works for the treatment of realgar (sulphide of arsenic), containing a small amount of mercury, the latter being recovered as metal and the former sold as refined orpiment. A very fine series of the products of these works, together with illustrations of work done by the attached bridge-building and engineering department, is contained in a special building in the open court on the west side of the Invalides building, with the bronze and iron castings from La Felguera, adjacent to it.

After a hearty vote of thanks to Professor Bauerman, the meeting was adjourned till Wednesday, 19th September, when the following paper was read :—

A NEW METHOD OF PRODUCING HIGH TEMPERATURES.

By ERNEST F. LANGE, F.C.S. (Manchester).

In the month of June last I was invited to Essen, in company with Mr. Henry Cooper, engineer to Messrs. Vickers, Sons, & Maxim, to witness some experiments introducing a new method for the production of high temperatures for certain metallurgical purposes, hitherto unobtainable except by means of the electric arc, this new method being the outcome of researches made by Dr. Hans Goldschmidt of that town.

The experiments, which were held at the works of the Chemische Thermo-Industrie Co., clearly showed to Mr. Cooper and myself that for various metallurgical purposes the engineer and chemist had now at their disposal a new and powerful agent sufficiently cheap and effective and sufficiently under control to justify its existence both from a practical and commercial point of view; and as but little had as yet been heard about the process in this country, I was asked by some of my friends in this Institute to bring the same more fully to your notice. Dr. Goldschmidt's kind consent and the Council's encouragement to the idea having been given, I thereupon set about the preparation of the following notes upon the process, which I trust will prove of service in making its merits more fully known to you.

The principle underlying the process is not new, as the same is based upon the heat energy developed by the chemical action of aluminium upon oxygen, or rather that between aluminium and certain metallic oxides: it is rather the manner in which this action is developed and its product applied which constitutes the novelty of the process.

The use of aluminium as a reducing agent has been known for many years. Shortly after its discovery by Wöhler of Göttingen, and its first production on a commercial scale by Henri Sainte-Claire Deville, who may justly be regarded as the founder of the aluminium industry, various experimenters showed that metals could be separated from their combinations by combustion with aluminium. Bunsen, Tissier, Michel, Beketoff, Rose, and others, not forgetting our own Dr. Percy, made experiments which in the aggregate demonstrated the reducibility of metals from their chlorides, fluorides, sulphides, oxides, and other compounds by means of aluminium. These observations were only carried out on a small scale, and were effected by crucibles placed in a small furnace, the reactions being often violent enough to scatter the contents of the same. In recent times Claude Vautin in London carried out an important series of experiments, wherein he showed that a long series of metallic oxides were reducible by aluminium. In his case also the reagents were heated by means of a crucible placed in a coke furnace. Again Messrs. Greene and Wahl of Philadelphia have for some years been producing pure manganese on a commercial scale by dissolving manganese oxide in molten cryolite and adding metallic aluminium thereto. Some very interesting laboratory experiments, showing the possibility of producing pure iron by reducing ferrous oxide with aluminium, were brought before this Institute at its Birmingham Meeting on August 21, 1895, by one of our Members of Council, whose services to the metallurgy of iron and steel have been of the most valuable kind—I allude to Robert Abbott Hadfield; and on March 15th in the same year our President, Sir William Roberts-Austen, gave a brilliant demonstration before the Royal Institution upon the "Reduction of the Rarer Metals from their Oxides," on which occasion several of the rarer metals were produced in some quantity by reduction with aluminium in a manner which appeared almost magical. Among other valuable investigations since then have been those of Moissan in producing aluminium alloys by the addition of metallic oxides to a bath of molten aluminium; and those of Kupelwieser and Matignon in determining the calorific effect of certain reductions with aluminium; and also the researches of Helouis in reducing vanadium, Duboin and Gauthier in reducing boron and silicon; and the interesting experiments of Francke, wherein he showed the reducibility of phosphorus from sodium phosphate by treatment with aluminium.

The researches of Vautin with the oxides led Dr. Goldschmidt to make further experiments, with the object of discovering a mode of controlling the violent reaction obtained by the heating of aluminium in contact with metallic oxides, and these brought to light the important fact that it was not necessary to heat the whole mass up to the requisite temperature for ignition, but that it sufficed to start ignition at any one point when, combustion once started, the reaction proceeded steadily with more or less speed throughout the whole mass, thus generating within itself the whole of the heat required for the action. In the case of the refractory oxides it would have been a difficult matter to apply the requisite heat for ignition at any point, had not Dr. Goldschmidt made the still more important discovery, that although certain oxides combined with aluminium at so low a temperature that they could be ignited with an ordinary match, yet they nevertheless in their combustion developed so much heat that if a small quantity thereof was placed upon a mixture of refractory oxide and aluminium and ignited, a reaction was started in the same which, thus originated, then proceeded automatically as before.

We will take, as example, the action of aluminium on iron oxide. If we mix together finely divided aluminium and oxide of iron in the proportion of their chemical equivalents, and start ignition at any point, we get a reaction which may be simply expressed as follows:—

$$Fe_2O_3 + Al_2 = Al_2O_3 + Fe_2$$

the products being alumina and iron. As no siliceous material can withstand the action of the hot alumina, a crucible lined with magnesite is preferably used. Into this crucible is first brought a little of the mixture for the reaction, and upon this is placed a good pinch of the igniting powder. This powder, as before said, consists of a mixture of aluminium and oxides with which it combines at a low temperature. For example, we may use barium peroxide mixed with a little magnesium or calcium carbide to make ignition more certain, or some of the nitrates or chlorates would do as well. The heat developed by the combustion of this mixture is sufficient to start the reaction between the aluminium and iron oxide mixture, and as this proceeds we keep adding more and more of the same, until within a minute or two of time we have a crucible containing reduced iron covered by a thick coating of alumina slag. The light emitted by the reaction is so intense that the eyes require the protection of dark glasses. On pouring off the slag, the temperature of the underlying liquid iron can be tried by pouring the same on to a mild steel plate, or along the side of a mild steel bar, when it will be seen that the hot iron cuts its way through with ease. Pyrometer experiments with the Wiborgh thermophone have established the temperature reached in the operation at about 2900° C. to 3000° C., that is to say, 1000° C. more than that reached during the hottest period of the Bessemer blow. In the case of the reduction of chrome from its oxide by this method, the temperature of 3000° C. is certainly reached, a temperature hitherto obtainable by the electric arc alone.

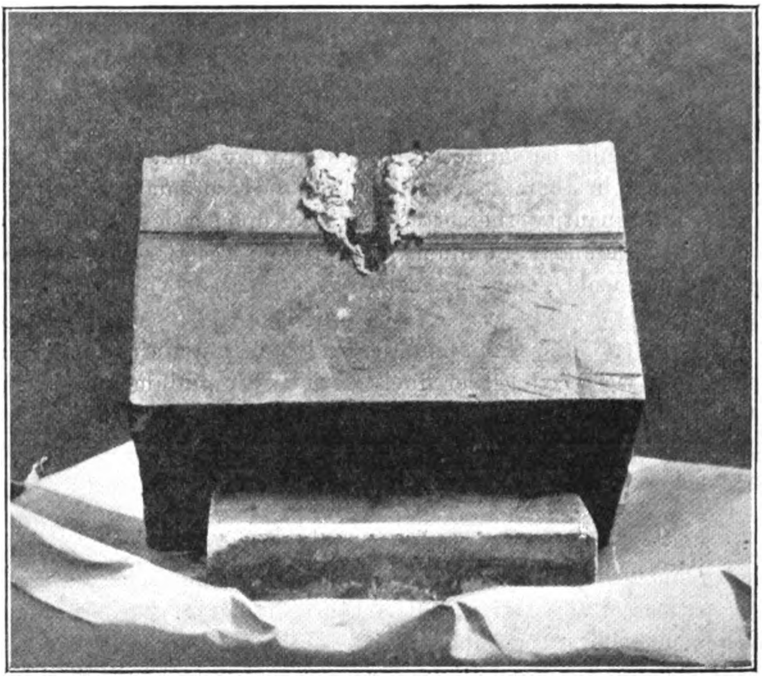


FIG. 1.—Block of steel, 10 in. thick, placed on edge, and partially molten through by the action of intensely hot fluid reduced iron.

Fig. 1, which is taken from a photograph, shows a 10-inch square block of steel partially molten through by an experiment as above described.

The work represented by the heat energy of these operations is also very high, as we may assume that the energy set free by the combustion of the aluminium is about equal to that originally used for the reduction of the aluminium in the electric furnace, so that in a reaction as above described, but requiring a crucible of 10 litres (610 cubic inches) capacity, thousands of horse-power are set free. Of course it will be understood that for many reasons more power must be used in the production of aluminium than is represented by the equation of the reaction.

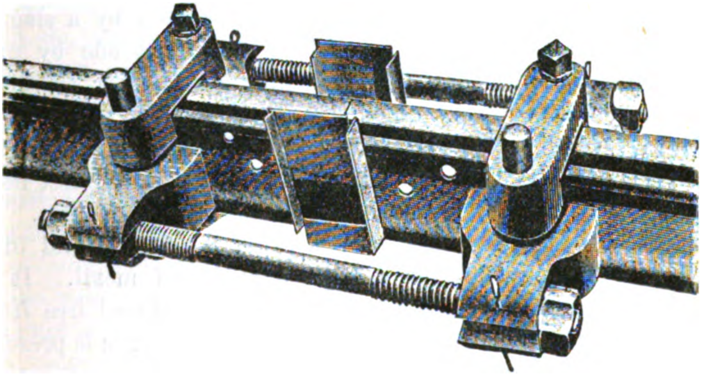


Fig. 2.—Shows the clamps used for rail-welding and the sheet-iron form round the joint for receiving the hot fluid.

It will doubtless occur to you that the crucible containing the reaction in progress may be likened to a poleless or secondary electric furnace, but having a much more speedy action. We must recognise the fact that in aluminium we have a very powerful source of heat, wonderfully condensed and portable and adaptable to many industrial operations. Aluminium and oxygen are two of the most common elements of which the earth's crust is composed, and it can hardly be questioned that the price of aluminium, already low, will be still further reduced as the years roll on.

Before passing on to speak of some industrial applications of the aluminium and iron oxide reaction, I must consider the use of the Goldschmidt process as applied to the production of certain metals and alloys of interest to the makers of steel and other material. In the first place, I will take the production of pure carbonless chrome and manganese.

The oxides of chrome and manganese are reduced to the pure carbonless metals in the following manner:—The oxide of the metal to be reduced is well mixed with aluminium. Some of the mixture is placed in a suitably lined crucible or tank and combustion started in the manner already described. In the same degree as the reaction proceeds, further additions of the mixture are made. In consequence of the intense heat of the reaction, there is a separation out of the pure metal in the liquid state, a result hitherto obtainable in the case of chrome by the electric arc alone, the liquid metal being covered by a slag of alumina. The reaction can be made a continuous one by providing two tap-holes, one for the metal and one for the slag. As the reaction is a very quick one, it is possible with only a moderately sized crucible to oxidise 1 to 2 kilos. of aluminium per minute, and as the products of combustion are almost non-gaseous, the reaction continues with wonderful smoothness. It is in this way possible, with quite a small floor-space and in a very short time, to produce a large quantity of metal. It is important to observe that the metal can be produced free from aluminium by providing that a small excess of oxygen is present, and also, that as aluminium is free from carbon, the metals thus produced also contain no carbon. This pure chrome is almost incorrodible, and possesses also very valuable electrical properties, but I shall only more nearly explain its value for the steel-melter.

As is well known, chrome is used for alloying with steel in the form of a high per cent. ferrochrome. These ferrochromes are distinguished by a high carbon content. This very fact limits, in cases, the amount of chrome that can be added, but by using a carbonless chrome the limits are accordingly increased. For some months at Essen and at the St. Michel de Maurienne Works, Savoy, such carbonless chrome has been made and sold for the production of chrome steel for armour plates and armour-piercing projectiles.

The manufacture of carbonless manganese is accomplished in the same manner as I have described in the case of the chrome. This manganese has certain advantages over the high per cent. ferromanganese; it does not disintegrate when exposed to the air, and it is particularly suitable for the manufacture of alloys of manganese with copper, tin, zinc, &c.; and it can also be used as a deoxidising medium instead of magnesium in the manufacture of nickel castings.

I might mention two other alloys of interest to steel-makers made by this method, namely, carbonless ferrotitanium with 10 per cent. and 20 per cent. to 25 per cent. of titanium, and also a carbonless ferroboron with 20 per cent. to 25 per cent. of boron. I may also remark that almost all the other metals can be similarly produced by reduction through aluminium; for example, tungsten, nickel, cobalt, molybdenum, titanium, boron, vanadium, uranium, and the more easily fusible tin and lead, also the metals of the alkaline earths barium, strontium, and calcium. We can also produce a compound of lead and barium, which resolves water, and a chrome manganese and a chrome copper, both of which can be made the basis of useful alloys. The most important exception among the metals irreducible by aluminium is magnesium, which, as Clemens Winkler demonstrated in the year 1890, is itself able to reduce alumina. Samples of the pure chrome, manganese, other metals, and alloys produced by this process are exhibited before you on the table. I may here mention that the molten oxide of aluminium, of which the slags produced in these reducing actions consist, is in itself a valuable substance, as it constitutes what is practically artificial corundum or emery, with the advantage over the latter that it contains no combined water, and thus makes a very hard grinding material. It also forms one of the few possible materials out of which crucibles for the reaction can be made. It is also valuable as a source of new aluminium for the smelters of that metal.

For all industrial purposes, where it is merely desired to make use of the heating effects produced by the oxidation of aluminium, the most effective and economical source of oxygen is that contained in the oxides of iron; and I must now draw attention once more to this reaction. It is above all suitable for producing heat for welding purposes. The operation is conducted by pressing together the two ends of the bars or pieces to be welded. There is then placed round the part to be welded, but separated from it by a fixed distance, a form made of thin iron sheeting, supported by being packed round with moulding sand. The aluminium-iron-oxide combustion is then effected in a crucible of fitting size, and the contents of the crucible poured into the form. As soon as the part to be welded has taken up sufficient heat, the weld is accomplished by pressing the two parts together by means of a suitable clamping arrangement.

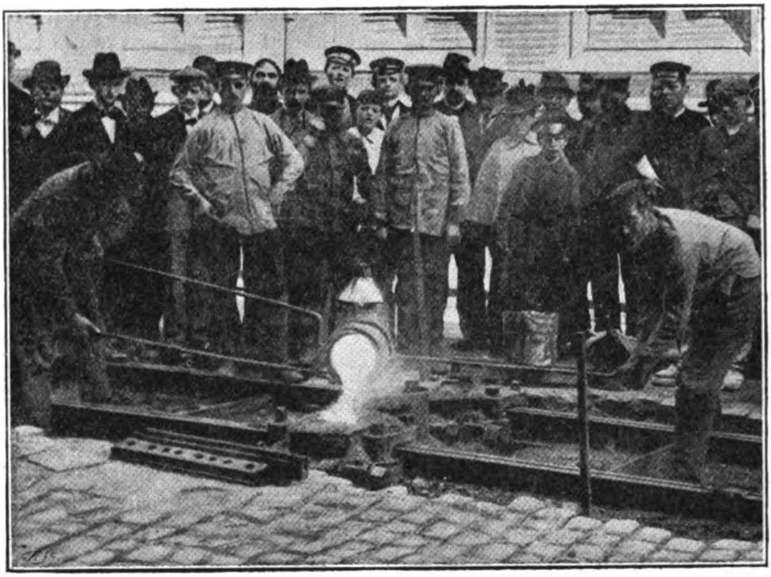


Fig. 3.—Rail-welding *in situ* for an electric tramway in Brunswick, May 1900. (From a photograph.)

It stands to reason that inasmuch as we require different degrees of heat for the various purposes to which the aluminium-iron-oxide reaction can be put, we can regulate the mixture in such a way as to obtain a greater or less heat from the oxidation of the aluminium. For example, we do not require the same temperature in heating or welding which we would for the reduction of the refractory metals. To this end we can dilute the iron oxide with sand, or magnesia, or lime. For the lower temperatures it is not even necessary to take pure aluminium, and a raw aluminium of 50 per cent. purity made from bauxite has a sufficient effect. Furthermore, when we require merely heat from the reaction, it is a matter of indifference as to how far the reduced iron is pure or impure. On the other hand, if it is proposed to use the reduced iron to form part of an iron or steel structure, the purity or composition of the same might prove an important matter. In this way we can obtain by more or less dilution of the heat-giving agents by neutral substances a reaction which will produce any desired temperature up to that produced by the most effective conditions for combustion. At the lower temperatures we would obtain merely a sintering mass, whilst at the higher temperatures the

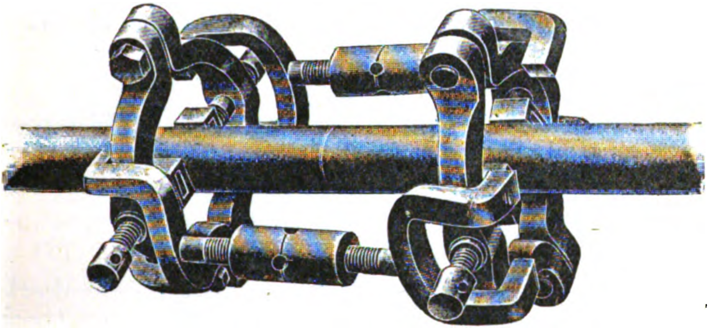


FIG. 4.—Shows the clamps used for welding tubes up to 4 inches in diameter.

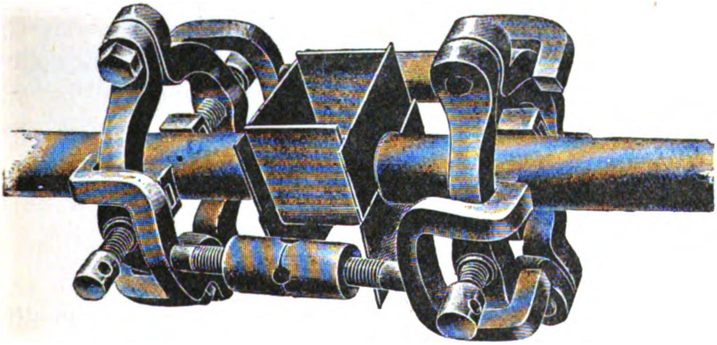


FIG. 5.—Tubes with casting form in position for horizontal welding.

slag is liquefied, and a regulus of metal formed beneath. In practice, however, it is better to use a high temperature reaction, taking for the lower temperature operations so much less of the reagents. Dr. Goldschmidt has found that two aluminium-iron-oxide mixtures serve for most purposes, and at the works of the Chemische Thermo-Industrie in Essen the manufacture of these on a large scale has been for some time in progress. To these mixtures the name Thermit has been given, the one used for welding is called Thermit P., and that used for the production of a pure iron or steel at the highest temperatures is called Thermit R., and the composition of these mixtures has been patented.

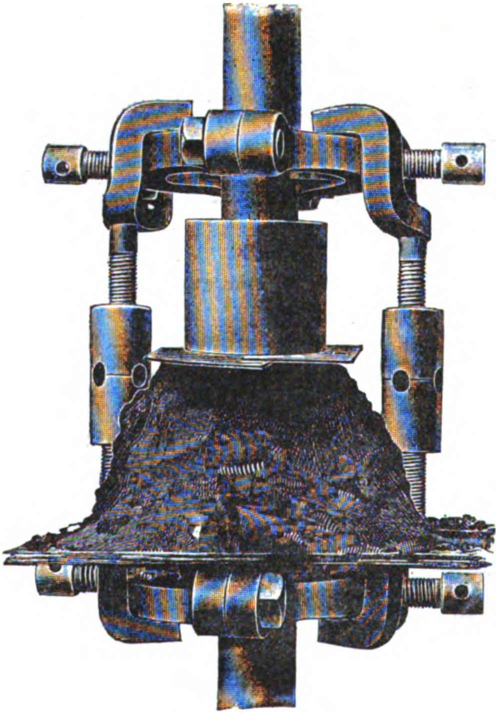


Fig. 6.—Casting form ready for filling for welding tubes in the vertical position.

Careful experiments have been made with a view to determine the amount of thermit necessary to heat up a given section of material to a welding heat, so that for a given piece of work the requisite size of crucible is known, and the welding calls for little skill or judgment on the part of the operator, and not more heat is produced than is necessary.

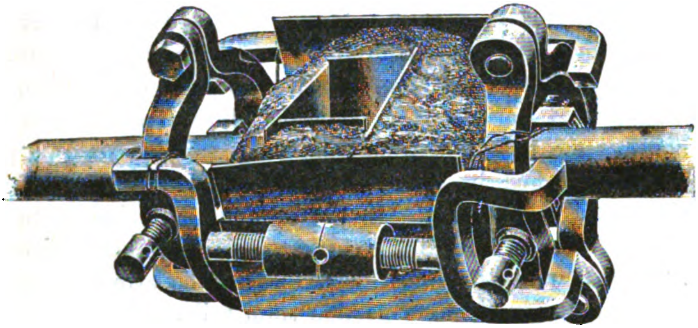


FIG. 7.—Shows the tubes in Fig. 5 completely ready for the welding operation.

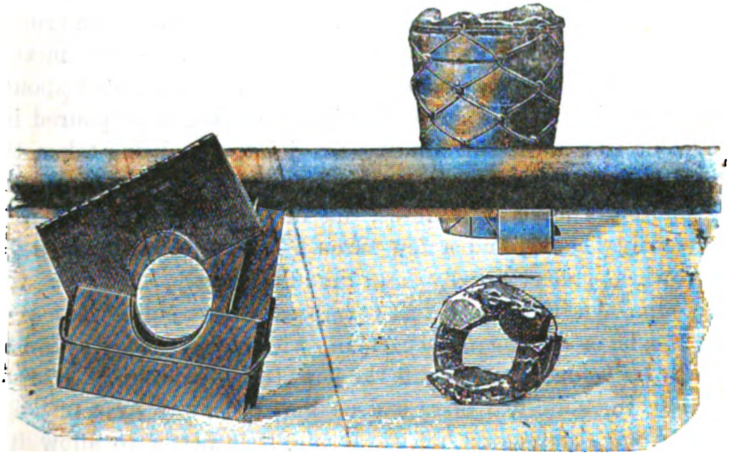


FIG. 8.—Shows the tubes in Figs. 5 and 7 welded, with casting form and mass knocked off, and showing the crucible used for the heat reaction.

It might be thought that there was some danger of fusion of the material when the thermit is first poured on, but the peculiar characteristic of the slag, in respect of its fire-resisting properties, prevents this. At the end of the reaction in the crucible there are two fluid layers, below the fluid iron and above the light fluid alumina. On emptying the crucible, the slag pours off first, and congeals in a thin layer on the cold surfaces of the sheet iron form and the material to be welded; the remainder of the slag and the whole of the iron poured out remain for some time fluid between the congealed linings of slag, which thus protect the form and weld from fusion. Two welding processes accomplished by this method I shall now proceed to describe more particularly. In the first place, I shall note the welding together of rails for electric, tram, and small railways. Figs. 2 and 3 will give you a close idea of the arrangement for welding in the case of heavy-section tram rails.

The rails which Mr. Cooper and myself saw welded were 7-inch girder rails. A good joint having been made between the two ends, strong clamps were then secured to the rails, some 9 or 10 inches from the joint, and connected with each other by means of a strong bolt on each side of the rail. The sheet iron form was then brought round the part to be welded, and backed round with fireclay. The reaction was then started in a crucible capable of taking 15 kilos. of the aluminium-iron-oxide mixture (thermit P), and at the end of the reaction, which lasted about a couple of minutes, the contents of the crucible were poured into the sheet iron form surrounding the joint, care being taken that the slag made first contact with the cold surfaces. After waiting another couple of minutes, the rail ends were judged to be sufficiently heated, and a few turns of the nuts on the tension-bolts were given equally and simultaneously, and the weld effected. An important feature about this welding process is that the layer of slag or corundum which first forms round the part to be welded also protects the joint from oxidation. After the welding, the solidified mass can be knocked away by a few light blows from a hammer; but, as a rule, it is better to allow it to remain on for some time, so as to allow of a more gradual cooling of the rail-joint. On knocking away the mass, it was seen that the sheet iron form was so little damaged that it could be used over and over again.

With regard to the comparative cost of the joint as compared with a fish-plate joint, Dr. Goldschmidt has got out some figures in which consideration is taken of the cost of maintenance of the fish-plate joint, and makes out a favourable case for the welded joint. I do not feel justified in giving figures based upon the limited experience of the welds in practice, but considering that trial lengths of electrical tramway rails in Essen, Brunswick, Hamburg, Berlin, Dresden, Plauen, and other towns, have been welded by the process described, reliable data should shortly be available. The reports of the same are hitherto of a favourable kind. It appears more than likely that this process will be largely used in the future for securing continuity of conductivity for the return current in electric railways. It is of great importance in the working of such railways that there is perfect electrical contact between the rails. The copper connections hitherto used are not altogether reliable, being apt to work loose.

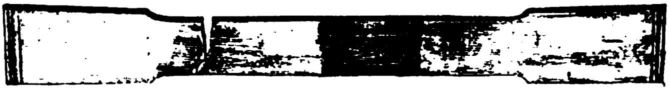


Fig. 9.—Tensile test made from the welded tube. The etched portion in the centre shows the line of weld.

Breaking load, 23·36 tons per square inch.
Elongation, 11·5 per cent.
A test of the unwelded material showed—
Breaking load, 22·73 tons per square inch.
Elongation, 15 per cent.

When this occurs, wandering currents of electricity make their return by way of the underground gas and water pipes, setting up a destructive electrolysis which can in time do much damage. Very unfortunate experiences have already been made in some of the United States cities from this cause. Experience with welded girder rails has shown that there is no danger to be feared from the effect of expansion or contraction due to climatic changes, as the concrete or paving in which these are buried equalise the temperature. In Fig. 3, which is taken from a photograph, there is shown the manner in which rails were welded in position for the Brunswick street tramways, and it will be seen that beyond some cases for holding the thermit and starting mixture, the clamping arrangement and the crucibles, nothing else in the way of apparatus was required.

With regard to the comparative cost of welding by thermit as against that of welding by electricity, it is hard to find common ground for a comparison, as the number of cases where electricity is sufficiently available and its use expedient is necessarily limited, and as far as I know, no comparison has been attempted. It is to be remarked that the fish-plate joint and copper strip connection has hitherto formed the standard practice for electric railways in all countries.

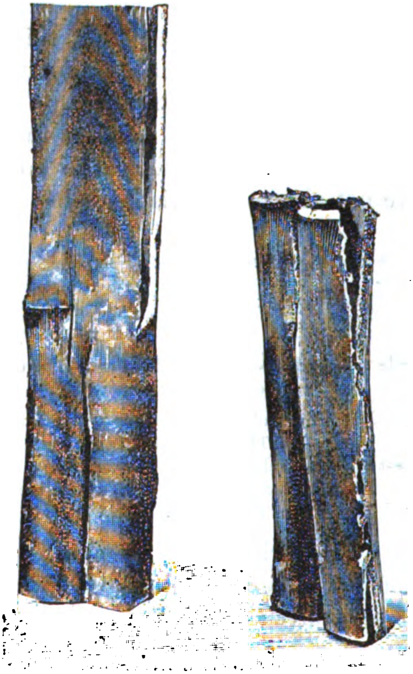


FIG. 10.—Shows welded tubes burst in the direction of their length by being hammered flat whilst the welded portion remains intact.

In order to give you a clearer idea than any words of mine can convey as to the speed and ease with which the rail-welding, as witnessed by Mr. Cooper and myself, was accomplished, I have prevailed upon Dr. Goldschmidt to kindly demonstrate the same to you at the conclusion of this paper by welding together before you in this room, without risk or danger of any kind, two short lengths of heavy girder rails.

As a second illustration of the utility of the new process for welding, I shall now mention the tube welding as witnessed by Mr. Cooper and myself. Figs. 4, 5, 6, 7, and 8, which are taken from photographs, will give you a very clear idea of the manner in which this is effected. The simple form and small sectional area of the tubes make welding of the same a much simpler matter than the welding of rails. The tubes shown in the illustrations are 50 mm. or two inches inside diameter and 4 mm. thick, and were each welded in a few minutes by the use of 1½ kilos. of thermit. Fig. 4 shows the tubes clamped and connected by tension screws. Fig. 5 shows the sheet iron casting form used. Fig. 6 shows a casting form backed up with sand and ready for filling for welding tubes placed vertically. Fig. 7 shows the casting form in Fig. 5 ready for the contents of the crucible. Fig. 8 shows the tubes in Figs. 5 and 7 welded together, with casting form and mass removed, and showing the crucible used for the reaction. We were informed that the strength of these welds was within a few per cent. of that of the unwelded portion for wrought iron, and that in the case of mild steel the weld had the same strength as the unwelded portion. Fig. 9, which is taken from a photograph, shows a tensile test made from a piece of welded wrought iron tubing. The etched portion in the centre shows the line of weld. The breaking load was 23·36 tons per square inch, with 11·5 per cent. elon-

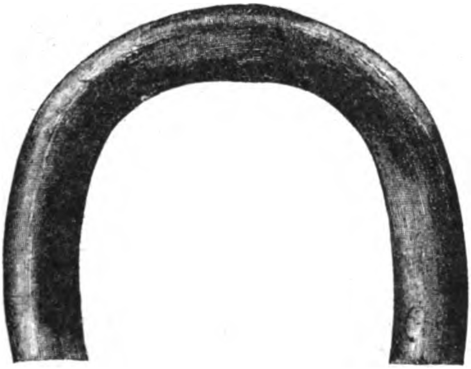


FIG. 11.—Welded tube bent cold about the weld.

gation, and a test of the unwelded material gave a breaking load of 22·73 tons per square inch with 15 per cent. elongation.

Figs. 10 and 11, taken from photographs, show further tube tests, showing the welded part intact after a flat hammering which has caused the rest of the tube to crack, and a welded tube bent round the weld without harm to the same.

In the new works of the Chemische Thermo-Industrie in Essen, the steam service pipes are all welded together on this system, and we were informed that this had proved a considerably cheaper method of joining the pipes than the use of flanges and bolts.

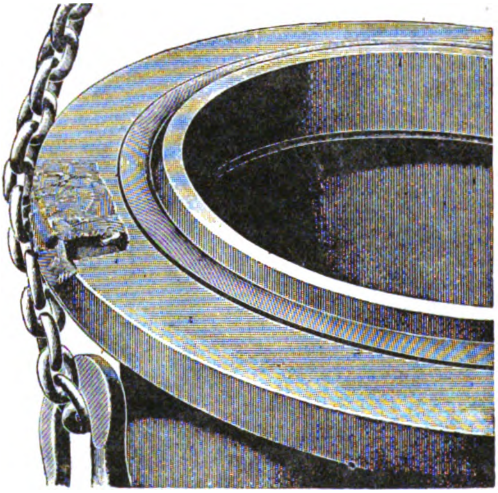


Fig. 12.—Repairing of a defective steel casting, showing piece cast on

Repairs were easily effected by cutting out the defective portion of the steel or iron tube and welding a new piece in position. In the same way junction and expansion tubes could be introduced where necessary. It would thus seem that the process should prove of considerable utility in the construction of many kinds of tube installations where, from one reason or another, the flanged joint is not perfectly reliable or convenient.

As before explained, the weld is protected from any destructive action from the thermit by the fact of the thin protective layer of slag or corundum which spreads itself over the parts to be welded. This slag coating also ensures freedom from oxidising influences on the weld. This fact has been turned to account by using thermit for giving the heat for effecting hard soldering and also for the welding of copper. For example, iron and copper, bronze and brass can be hard soldered by the heat of thermit suitably applied.

Another interesting application of the heat given by thermit is that of the softening of armour plates in places where it is desired to drill holes. This is effected in the simplest possible manner by pouring a small quantity of the hot fluid thermit into a form placed upon the part desired to be softened. The heat quickly penetrates into the body of the plate, softening the chilled carburised surface, which can, after a short interval of waiting, be drilled as required. This also was effectively demonstrated to Mr. Cooper and myself.

I have finally to mention the use of thermit for the production of small quantities of very hot metal for the purpose of repairing defective steel castings, or for the thickening of any part of a steel piece where additional metal is found to be necessary. This is done by taking a suitably sized crucible and starting the thermit reaction in the usual way. On the reaction being completed, the slag is very carefully poured off, and with the very hot and fluid metal that now remains, the blowhole is filled up, or the defective part built up, as the case may be, the metal being guided by a small mould of ganister. A convenient feature of this process is the facility with which the reduced iron or, to be more accurate, steel, can be made to resemble in composition the piece to which it is applied, for we can mix with the thermit beforehand silicon, manganese, or chrome, to give to the steel a certain definite composition. It, however, seldom happens that the office to be performed by the small quantity of molten steel is such as to make this an important matter. The chief consideration is, that it should set solidly. For most cases, therefore, the standard mixture of thermit made at Essen for this purpose, and designated thermit R in contradistinction to the first-named thermit P, will be found efficient.

You will see on the table a piece of 1 inch thick steel frame plate which has been thickened up to $2\frac{1}{8}$ inches by this method. Figs. 12 and 13, which are taken from photographs, show, in the first place, a steel cylinder with a defective place on the flange which has been filled up with the steel produced by thermit R, and secondly, a spur-wheel with broken teeth, showing the rough portion re-cast from thermit in the one case, and the machined portion in the other.

I regret that I have not yet been able to complete certain investigations I have entered upon to determine the mechanical and other properties of this alumino-genetic iron. Micro-structure investigations would doubtless prove interesting as well, but I hope to be able to include some of them later on in the Proceedings of the Institute. I hope, however, that this account of the heat-producing properties of thermit, and the uses to which it can be put, will induce some of you to take up some of these interesting experiments for yourselves. I think it will be clear from what I have related, that two new uses for aluminium have been called into existence for the benefit of industry, both of which rest upon the, as yet,

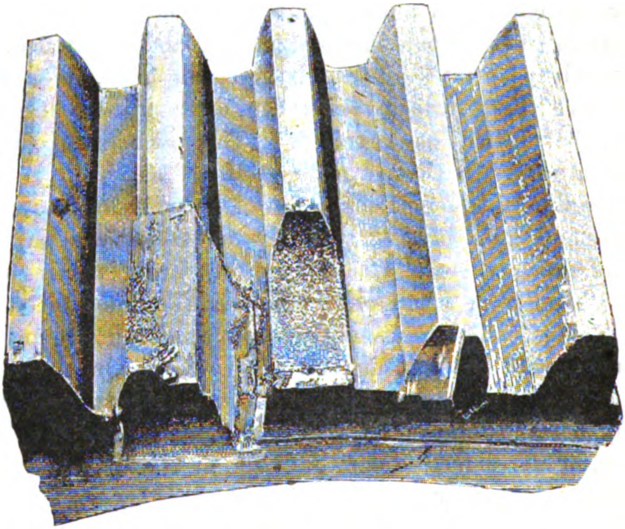


Fig. 13.—Spin-wheel with broken teeth, showing machined and unmachined cast on new portions.

unsuspected property of aluminium as a heat accumulator, whereby it is rendered possible to release in the form of heat, everywhere and with the greatest of ease, the work which was required for the original production of the aluminium. Another thought is not far removed from this, namely, the possibility of using aluminium, not only for the processes described, but to discover a means of turning the heat of combustion of the aluminium back into electricity for the production of power. It is, indeed, possible that in the future the value of aluminium will lie, not altogether in its properties as a metal, but also as a power-accumulator of the highest efficiency.

In conclusion, I have to thank Dr. Goldschmidt for the valuable assistance he has given me in the preparation of this paper, and for the loan of the photographs from which the illustrations have been prepared, and for his trouble in coming here to-day to make an experiment before you; and I have also to express once more to him, on behalf of Mr. Cooper and myself, our thanks for the courtesy received at his hands during our visit, and the facilities which he afforded to us for studying his process.

DISCUSSION.

The **President** stated that the experiments showed how wonderfully quickly the whole aluminium-iron-oxide reaction proceeded.

The **President** then invited discussion.

Mr. J. E. **Stead**, Member of Council, asked if the metals produced by reducing the oxides were free from aluminium? He thought this process was admirably adapted for making quantities of alloys such as any chemist might wish to experiment upon, but it was very important that the alloys should be absolutely free from the aluminium.

Sir **Lowthian Bell**, Bart., Past-President, thought this process might have another valuable application to those already mentioned by Mr. Lange. The Electric Department of the Post-Office was, and he had no doubt still was, most desirous to obtain iron absolutely free from carbon. The smallest trace of carbon was enough to convert the iron they used into a permanent magnet which interfered with its sensibility in transmitting messages, causing considerable waste of time; and it was possible that the iron free from carbon might fulfil the conditions that Sir William Preece was labouring after, and unsuccessfully, for some time.

Mr. **Edward Riley** said the steel made now was practically free from carbon. The North-Eastern Steel Works made the rail for the Central Railway in London, and the guaranteed condition was that the conductivity was to be equal to one-seventh that of copper, and they succeeded in making a steel equal to that practically free from carbon. He should like to ask Mr. Lange about the peculiar smell caused by the experiment in the room. At first it seemed like an arsenic, but it might be hydrocarbon. They might possibly remember that many years ago the late Mr. Robert Mushet laid very great stress upon alloys of titanium in steel. For many years that was held as a sort of theory, but for his own part he was not able to find it in steel. It existed in cast iron to a certain extent. But having now those very easy methods of getting alloys difficult to reduce, he would suggest whether it would not be possible to try and reduce titanium. Mr. Mushet's theory was completely played out, but it might be advantageous to try the experiment. They knew the nitrate of titanium in the old blast-furnace (which was not really a metal), and he suggested that, with their means at present, it might be possible to ascertain whether titanium really could be made to alloy with steel.

Mr. G. J. **Snelus**, Vice-President, thought if Mr. Riley would examine one of the cases in the German Section of metallurgical exhibits, he would find a sample of ferro-titanium produced by aluminium. It was quite worth while for the members to examine these wonderful exhibits of rare metals in the Exhibition, which had been produced on a large scale in Germany; and he understood that all the metals were produced by reducing the oxides with aluminium.

Mr. H. **Le Neve Foster** asked if it was necessary to use the aluminium in very fine powder or as a mixture of fine powder and aluminium turnings?

The **President** said he had had some experience with the reduction of the rare metals by means of finely divided aluminium, and he had demonstrated the fact at the Royal Institution many years ago. There was a point which he should like to indicate on the black-board, and that was the extreme sharpness with which the reaction took place. Supposing this material undergoing reduction in the crucible; if they took a thermo-couple and placed it in it and brought its ends in connection with a galvanometer, a light would be thrown from the mirror, and the galvanometer would tell for any particular substance the exact moment at which the reaction took place. The moment it reached a certain point (indicated) the reaction would begin, and evolution of light and heat would take place, as they had already witnessed in Dr. Goldschmidt's experiment.

In the case of the uranium, he forgot whether they could reduce the oxide. At any rate, he had failed to get coherent matter, and he had also failed with titanium, mainly because it had such an attraction for nitrogen, that unless exceeding care were taken, it combined with the nitrogen of the air. The experiments were of the greatest possible interest, and no one was more sorry than he was that they could not be carried out in that room with safety under the present conditions.

Mr. LANGE, in reply, said that they could see samples in the Exhibition of most of the metals which had been reduced by this process, as had been stated by Mr. Snelus. The exhibit that Mr. Snelus had referred to was that of Dr. Goldschmidt's, and therefore, as a continuation of all that they ought to have seen in that room, it would be found very interesting. In that exhibit they would find the results of a large number of experiments, including some similar to what they had hoped to show to-day. There they would see welded tubes, welded girder rails, and the thickening up of plates by the pouring on of reduced metal, and test-pieces and broken tubes showing the strength of the material, and also pure manganese and chrome in large masses, and also samples of almost all of the metals which had been reduced by this process. The question asked by Mr. Riley in respect of the titanium had been answered by Mr. Snelus. With regard to the smell in the room, which Mr. Riley asked about, he had noticed the same thing himself in experiments with this mixture, and he felt sure that this curious smell was due to some hydrocarbon, or even a sulphur compound; but what it was he did not know. With regard to the process, it was yet very new, and they had to further investigate the process both chemically and mechanically, and experiments of great interest were still going on. Mr. Foster had asked whether fine aluminium and aluminium turnings mixed would do instead of having all the aluminium in a fine state of division. Well, he did not think that the aluminium turnings would do, because it was perfectly essential that the heat should be developed in the shortest possible time, otherwise they would not get the temperature, and they must have the most exact mixture of oxide and aluminium, and therefore both had to be in a fine state of division. He might refer to one experiment that Dr. Goldschmidt had hoped to make, viz., the welding together of a couple of heavy girder rails, and he was particularly sorry that the surroundings of the room prevented this from being attempted, as the experiment had been easily effected in other rooms before to-day. He would have shown a couple of 7-inch girder rails welded in the space of a few minutes. They would, however, see before them on the floor a couple of rails which had been welded showing the finished weld, and another couple on which the congealed mass of thermit was only partially removed, from which they would see that the actual section of heating material was but small considering the effect produced. As time was becoming pressing, he would prefer communicating his answers to the other interesting points raised by Sir Lowthian Bell, Mr. Stead, and other speakers by letter to the Secretary. In conclusion, Mr. Lange thanked the members for the very kind manner in which they had received his paper.

After the meeting Mr. Lange sent the following communication to the Secretary:—

I have yet to make good certain omissions in my reply to the discussion raised upon my paper.

I will first take Mr. Stead's question as to whether the metal produced was free from aluminium. To this I might reply that Dr. Goldschmidt claims that, by providing a small excess of oxygen, all the aluminium is consumed. This I have not found to be the case with the thermit I have hitherto received from Essen; but as I have had no difficulty myself in making a mixture that did consume all but a trace of aluminium, I imagine that there was something not quite normal in the material supplied. I cannot, however, help thinking that in practice there will always be a chance of some of the aluminium alloying itself with the metal. In many cases this might not matter, but in others it might. The continual experimenting that is going on ought to show soon with what certainty the combustion of all the aluminium can be effected. I do not think that the idea suggested by Sir Lowthian Bell of the utility of the process in providing a pure iron for electrical purposes is a possible one, as the cost would be too great. Very pure iron can be produced on a large scale by the basic open-hearth process, and very cheaply, whilst with the process under review no purer iron could be produced on a commercial scale, owing to the difficulty in finding sufficiently pure iron oxide and also crucible lining material, having regard to the intense reducing power of aluminium. In Mr. Hadfield's Birmingham paper, alluded to in the opening of my paper, there are described certain laboratory experiments which had as their object the production of pure iron by reducing specially prepared pure oxide and oxalate of iron with aluminium. An iron of between 97·50 per cent. and 97·75 per cent. purity was obtained at a cost of about 1s. 6d. per pound. This percentage of purity attracted the attention of Dr. H. Wedding of Berlin, who wrote to draw attention to the fact that this iron was not so extraordinarily pure, considering that the iron used by the Iron Alloys Committee of one of the German societies for the preparation of nickel iron alloys had been made in quantity in an ordinary basic open-hearth furnace by F. Krupp at Essen, and was of 99·71 per cent. purity. It would appear, therefore, that the basic open-hearth furnace, melting pure materials, would always be a cheaper producer of pure iron than any reduction process by aluminium.

The PRESIDENT said they would all give a hearty vote of thanks to the author of this very valuable paper. There was one very interesting feature of the reaction, as was mentioned by Mr. Lange, viz., the absence of non-gaseous products, and the oxides produced as slags had many remarkable characteristics.

The following paper was then read:—

AMERICAN STANDARD SPECIFICATIONS AND METHODS OF TESTING IRON AND STEEL.

BY ALBERT LADD COLBY.

A. HISTORICAL INTRODUCTION.

THE first successful effort in America to standardise specifications for iron and steel was made in August 1895 by the Association of American Steel Manufacturers, a technical organisation formed to discuss matters pertaining to the manufacture and use of steel. These specifications were revised by the Association on July 17, 1896. They included specifications for structural steel, special open-hearth plate and rivet steel, and structural cast iron.

Although these specifications were criticised and referred to by the technical press and engineers as "manufacturers'" specifications, they nevertheless grew in favour among engineers and consumers when it was appreciated that just as good steel for the various purposes intended was furnished on these specifications as on engineers' specifications containing numerous other stipulations unnecessary in the present state of the art of making steel. These specifications also accomplished the important work of convincing engineers and customers that more prompt deliveries, and more close competition among manufacturers, was possible on standard specifications containing only such requirements and tests as necessary to ascertain that a satisfactory steel was being furnished, and omitting many useless tests which only serve to add to the expense or cause delay in manufacturing operations.

The formation of the American Section of the International Association for Testing Materials on June 16, 1898, gave an excellent opportunity for engineers, consumers, and manufacturers to come together with a view of framing American standard specifications covering all the various kinds of iron and steel, for among the twenty-two problems which were presented by the parent Association, problem No. 1 asked the American Section to co-operate in establishing "international rules and specifications for testing and inspecting iron and steel."

Under authorisation of the Executive Committee, the American Branch of Committee No. 1 was increased to thirty-four members, half of whom were engineers, professors in technical schools, consumers of steel, or delegates from scientific societies, and half representatives from the leading American manufacturers of the various kinds of iron and steel.

This Committee has held frequent meetings since March 9, 1899. Its sub-committees have collected and tabulated the requirements of existing American specifications which have been used as a basis in framing the ten proposed American standard specifications, which were discussed, revised, and finally endorsed as representative of the best American practice, by letter ballot, practically all members voting in favour of the specifications. Having had the benefit of criticism from leading technical societies and journals during the summer, they will be brought before the International Association for Testing Materials at its third annual meeting next October, for discussion and adoption, perhaps after some revision, as American Standard Specifications. They will then be forwarded to the chairman of the International Committee No. 1 of the International Association for Testing Materials, with the tables of existing specifications on which they were based.

If each national branch of Committee No. 1 proceeds on these lines, international specifications, at the next Congress of the International Association for Testing Materials, may be realised, but even if this is found impossible, much will have been accomplished, in each country, by the adoption of national standards.

As these specifications embody the results of over a year's conscientious work by a Committee of prominent Americans, representing all interests, the writer was asked to prepare for this meeting of the Institute a critical review of the requirements contained therein. A comparison of the nine specifications for steel may be most conveniently accomplished by using the eight uniform headings found in each specification. The specifications for wrought iron will not be discussed.

A list of these ten specifications is as follows:—

Steel castings.
Steel axles.
Steel forgings.
Steel tires.
Steel rails.
Steel splice bars.
Structural steel for buildings.
Structural steel for bridges and ships.
Open-hearth boiler plate and rivet steel.
Wrought iron.

B. THE PROCESSES OF MANUFACTURE SPECIFIED.

The processes of manufacture called for in the nine steel specifications are conveniently shown by the following statement:—

Specification for	Open-hearth Process.	Crucible Process.	Bessemer Process.
Steel castings	Open-hearth.	Crucible.	Bessemer.
Steel axles	Open-hearth.	...	...
Steel forgings	Open-hearth.	Crucible.	Bessemer.
Steel tires	Open-hearth.	Crucible.	...
Steel rails	Open-hearth.	...	Bessemer.
Steel splice bars	Open-hearth.	...	Bessemer.
Structural steel for buildings . . .	Open-hearth.	...	Bessemer.
Structural steel for bridges and ships .	Open-hearth.	...	...
Open-hearth boiler plate and rivet steel	Open-hearth.	...	...

1. *Details of Processes should not be Specified.*—With one exception, these nine specifications for steel very properly omit all restrictions as to details of the processes of manufacture, partly because they were framed with a view to their possible adoption as international specifications, and processes necessarily vary in different countries, and also because it is, in general, outside of the province of the engineer to specify the details of metallurgical processes when he is afforded by the manufacturer every reasonable facility to satisfy himself whether or not the finished material is in accordance with the specification. The

following clause from the specification for steel rails constitutes the exception above referred to:—

"The entire process of manufacture and testing shall be in accordance with the best current practice, special care being given to the following instructions:—Ingots shall be kept in a vertical position in pit-heating furnaces; no bled ingots shall be used; sufficient material shall be discarded from the top of the ingot to insure sound rails."

As far as American practice is concerned this clause is unnecessary, as the details of the process specified are carried out in the everyday practice of every rail-mill in the United States.

If an engineer prefers acid rather than basic open-hearth steel, it is perfectly proper for him to so specify. Of course, he restricts competition and increases the cost of his structure. If he desires the finished material annealed, it is also proper for him to so define the process of annealing, that it shall not include a slow cooling from the initial temperature of casting or rolling or forging. It is, however, plainly outside of the territory over which he has jurisdiction for him to specify the composition or character of the raw materials, or the proportion of scrap which may be used, or any other details of manufacture. Furthermore, conscientious inspection, under specifications governing the details of nearly every step in the manufacture, is utterly impossible within the cost of inspection allowed by the engineer or contractor. The requirements of a specification governing the details of the process of manufacture are therefore often openly ignored by both manufacturer and inspector.

2. *Annealing.*—Reference to this important process for the removal of the internal strains unavoidably present in such finished material as steel castings, steel forgings, eye-bars, and plates has been to a large extent omitted in the steel specifications under discussion, so as to leave the customer free to add it to the requirements called for, if he desires a better material and is willing to pay the additional cost; or free to definitely specify that his material shall *not* be annealed, in case he fears, as is unjustly claimed by some engineers, that the annealing process will be used by the manufacturer to bring an inferior material within the physical requirements specified. As before stated, it is perfectly proper for the engineer to specify that slow cooling

from the initial temperature of casting, rolling, or forging shall not be considered annealing, for such a cheap substitute for true annealing enlarges the grain and therefore weakens the steel. Further than this, however, it is better for him to increase the required percentages of elongation and contraction of area than to attempt to specify the temperature to which the steel shall be reheated, or other details of the annealing process.

C. THE CHEMICAL PROPERTIES SPECIFIED.

3. *Chemical Requirements.*—Table II. gives the chemical requirements of the nine specifications under discussion. Where tensile strength is specified, limits in carbon have been purposely omitted, except in the case of splice bars, where a carbon limit is included for the reason that the specified physical properties are seldom actually called for. Limits in manganese are included in the case of tires, boiler plate and rivet steel, splice bars and rails, and silicon only in the case of tires and rails. Phosphorus is very properly specified in all the different classes included in the nine steel specifications, and sulphur in all but rail steel and structural steel for buildings. No limit in copper has been specified, as it has been conclusively proved * that it exercises no deleterious influence even when present in greater proportions than found in the steel made in certain localities in the United States partly dependent on ores carrying small quantities of this ingredient.

4. *Carbon not Specified.*—The omission of carbon when tensile strength is specified is in accordance with the latest and best views on this subject. Instances might easily be cited from existing specifications where the tensile strength specified could not be met if the required limits in carbon, and in some cases manganese and silicon, were adhered to in the selection of the steel. Where the physical properties desired are clearly and properly specified, the chemistry of the steel, other than prescribing the limits of the injurious impurities, phosphorus and sulphur, may in the present state of the art of making steel be safely left to the manufacturer.

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* H. H. Campbell's "Manufacture and Properties of Structural Steel," New York. 1896, pp. 274, 275. "Copper in Steel," by Albert Ladd Colby. *The Iron Age*, vol. lxiv., November 30, 1899, pp. 1-7.

TABLE II.—*Required Limits in the Chemical Composition of Steel.*

Specification for		Carbon per Cent.	Manganese per Cent.	Silicon per Cent.	Phosphorus not over per Cent.	Sulphur not over per Cent.	Nickel not over per Cent.
Steel castings	Ordinary castings	Not over 0·40	...	...	0·08	...	...
	Tested castings	...	...	...	0·05	0·05	...
Steel axles	Car, engine truck, and tender truck	...	...	...	0·06	0·06	...
	Driving wheel (carbon steel)	...	...	...	0·06	0·06	...
	Driving wheel (nickel steel)	...	...	...	0·04	0·04	3·75
Steel forgings	Of soft or low carbon steel	...	...	...	0·10	0·10	...
	Of carbon steel, not annealed	...	...	...	0·06	0·06	...
	Of carbon steel, oil-tempered or annealed	...	...	...	0·04	0·04	...
	Of nickel steel, oil-tempered or annealed	...	...	...	0·04	0·04	3·75
Steel tires	...	...	Not over 0·80	Not under 0·20	0·05	0·05	...
Structural steel for buildings, including rivets	...	...	...	...	0·10	..	...
Structural steel for bridges and ships, including rivets	Acid-open hearth	...	...	...	0·08	0·06	...
	Basic open-hearth	...	...	...	0·06	0·06	...
Open-hearth boiler plate and rivet steel	Flange or boiler steel	...	0·30–0·60	...	0·06	0·05	...
	Fire-box steel	...	0·30–0·50	...	0·04	0·04	...
	Extra soft steel	...	0·30–0·50	...	0·04	0·04	...
Steel splice bars	...	Not over 0·15	0·30–0·60	...	0·10	...	...
Steel rails of weight per yard specified	50 lbs. to 59+lbs.	0·35–0·45	0·70–1·00	Not over 0·20	0·10	...	...
	60 lbs. to 69+lbs.	0·38–0·48	0·70–1·00	Not over 0·20	0·10	...	...
	70 lbs. to 79+lbs.	0·40–0·50	0·75–1·05	Not over 0·20	0·10	...	...
	80 lbs. to 89+lbs.	0·43–0·53	0·80–1·10	Not over 0·20	0·10	...	...
	90 lbs. to 100 lbs.	0·45–0·55	0·80–1·10	Not over 0·20	0·10	...	...

D. THE PHYSICAL PROPERTIES SPECIFIED.

5. *Tensile Strength.*—In all the specifications, except for steel rails, limits in tensile strength are specified. For the structural steels, boiler plate and rivet steel, and splice bars, a range in tensile strength of 4·46 tons (10,000 lbs.) per square inch is specified, as shown in Table III. In all other specifications minimum requirements are given. The tensile tests required on full-sized eye-bars are given in the specification for structural steel for bridges and ships.

Tensile strength is specified in order to insure the necessary strength in the material. The elastic limit is, however, the true index of resistance to working stresses. In material uniformly heated before rolling, a large number of tests have proved that the elastic limit practically never falls below 50 per cent. of the tensile strength. As its accurate determination is an impossibility in rapid commercial testing, the tensile strength is relied upon to indicate the elastic limit, with which information the stresses which may be successfully carried can be safely computed.

The yield point as determined in commercial testing furnishes a desirable check on the accuracy of the assumption that the elastic limit of the material under consideration is at least one-half of the tensile strength.

6. *Yield Point and Elastic Limit.*—As shown in Table III., the yield point is required wherever tensile strength is specified, except in the case of steel tires. In the specification for steel forgings, in the case of annealed and oil-tempered carbon steel and nickel forgings, elastic limit is called for instead of yield point.

7. *Elongation.*—The percentage of elongation required is measured in 8 inches in the structural steels, boiler plate and rivet steel, and splice bars, and in 2 inches in castings, axles, forgings, and tires. The required percentages of elongation are shown in Table III. In the specifications for structural steel for buildings and for bridges and ships, and in boiler plate and rivet steel, certain modifications are noted for thin and thick material and for pins.

Elongation, in the large majority of commercial steels, is a

TABLE III.—*Required Limits in the Physical Properties of Steel.*

Specification for			Tensile Strength. Tons per Square Inch.	Yield Point. Tons per Square Inch.	Elongation per Cent. See Note (*e*).	Contraction of Area per Cent.	Bending Test. D=Diameter. T=Thickness.
Steel castings	Ordinary castings		...	...	...	...	...
	Tested castings	Hard	37·94	17·08	15	20	...
		Medium	31·25	14·06	18	25	90° D=2 T
		Soft	26·78	12·05	22	30	120° D=2 T
Steel axles	Car, engine truck, and tender truck		...	...	...	...	...
	Driving axles (carbon steel)		35·71	17·85	18	...	...
	Driving axles (nickel steel)		35·71	22·32	25	45	...
Steel forgings	Soft or low carbon steel		25·89	12·95	28	35	180° D=T
	Carbon steel, not annealed		33·48	16·74	18	30	180° D=3 T
	Carbon steel, annealed		See Specifications.		Physical qualities vary with diameter of the forgings. (See Note *c*.)		
	Carbon steel, oil-tempered						
	Nickel steel, annealed						
	Nickel steel, oil-tempered						
Steel tires	Passenger engines		44·64	...	12	...	...
	Freight engines and car wheels		49·11	...	10	...	...
	Switching engines		53·57	...	8	...	...
Structural steel for buildings	Rivet steel		22·32 to 26·78	13·39	26	...	180° Flat
	Medium steel		26·78 to 31·25	15·62	22 See Note (*b*)	...	180° D=T

Structural steel for bridges and ships.	Rivet steel	22·32 to 26·78	13·39	26	...	180° Flat
	Soft steel	23·21 to 27·68	14·29	25	...	180° Flat
	Medium steel	26·78 to 31·25	15·62	22 See Note (*b*)	...	180° D=T
Open-hearth boiler plate and rivet steel . . .	Flange or boiler steel	24·55 to 29·02	14·73	25	...	180° Flat See Note (*d*)
	Fire-box steel	23·21 to 27·68	14·29	26	...	180° Flat See Note (*d*)
	Extra soft steel	20·09 to 24·55	13·39	28 See Note (*b*)	...	180° Flat See Note (*d*)
Steel rails . .	See Note (*a*)	...	...	...	...	...
Steel splice bars .	...	24·11 to 28·57	14·29	25	...	180° Flat

(*a*) This Table does not include the drop test required on castings, axles, tires, and rails; the homogeneity test for fire-box steel; nor the percussive test for large steel castings.

(*b*) This Table does not include the variations in elongation allowed for thick and thin structural steels and boiler steel, nor the tensile tests of full-sized eye-bars.

(*c*) In the four classes of steel forgings not tabulated above, elastic limit is specified instead of yield point.

(*d*) These same bending tests are required after quenching.

(*e*) The elongations given for castings, axles, forgings and tires, are on 2″, the others are on 8″, gauged length.

safe index of ductility. In the present state of the art it is a safe check, where only minimum tensile strength is required, against the use of a steel too high in carbon or other hardening elements for the purpose intended. The ease with which the determination can be made on rolled material makes it valuable and desirable in the commercial testing of large output, where rapidity as well as accuracy of testing is demanded.

8. *Contraction of Area.*—The percentage of contraction of area is included in the requirements for castings, axles, and forgings where the tensile strength is determined on a turned test specimen. It was omitted from the specification for tires, where a turned specimen is also used, because it was considered an unnecessary requirement in testing the high carbon steel used in this case, as the tires are very seldom annealed.

The value of this determination as an index of the quality of steel is fully appreciated by those who have made a comparative study of microscopical structure, and the accompanying physical properties as determined on turned specimens. The uniformly fine-grained micro-structure, only attained when a proper heat treatment has given to the steel the best physical qualities, is invariably accompanied by the highest percentage of contraction of area obtainable with any given class of steel.

9. *Bending Tests.*—No bending test is included in the specifications for axles, tires, and rails. The bending tests required in the other six steel specifications are compared in Table III., where the letter "T" denotes the thickness of the bending test specimen, and the letter "D" the diameter of the piece around which it is bent. For open-hearth boiler plate and rivet steel the bending tests given in the table are required after the specimen has been quenched as well as in the natural condition. In all other cases the cold bending tests given in the table are to be made on untreated bending specimens cut from the finished material.

The cold-bending test is a valuable indication of the structure of the metal, and in this respect bears a close relation to the contraction of area. The two are indications of the same quality in the steel, namely, its capacity for cold flow. A steel having a high contraction of area will always stand severe cold bending, and, conversely, a steel capable of severe cold bending will always show high contraction of area. This makes the cold-bending test particularly valuable, as an indication of the structure of the metal, in cases where there is any difficulty in obtaining a true and ready measure of the contraction of area.

10. *Drop Tests.*—The specifications for axles, tires, and rails call for a drop test, and in the specification for steel castings it states that a test to destruction may be substituted for a tensile test in the case of small or unimportant castings. None of the other specifications include a drop test.

An axle must stand a certain number of blows at specified heights without rupture and without exceeding, as the result of the first blow, a given deflection. These varying requirements for each diameter of axle are given in the specification. A tire must stand, without breaking or cracking, successive blows from increasing heights until it shows a deflection equal to $D^2 \div (40\ T^2 + 2D)$, in which "D" is the internal diameter of the tire and "T" the thickness at centre of tread. A rail must not break or crack under a single blow on the head from heights varying with the section of the rail, as follows:—

Weight of Rail. Pounds per Yard.	Height of Drop. Feet.
45 to and including 55	15
More than 55 „ 65	16
„ 65 „ 75	17
„ 75 „ 85	18
„ 85 „ 100	19

The features of the drop-testing machines, subject to specification, are referred to in paragraph 23.

Drop tests were included in the specifications for axles, tires, and rails, as it was fully appreciated by the Committee that material which will be submitted to shocks when in actual use should be tested by impact. In each case the drop test adopted is in accordance with general American practice, which, after a number of years' experience, has been found to give very satisfactory results.

11. *Homogeneity Test.*—This test is confined to fire-box steel. Its object is to show the uniformity of the metal, that is, freedom from closed or partially welded blowholes, pipe, or slag. A

sample taken from a broken tensile specimen shall not show any single defective flaw or slag streak more than a quarter inch long in any of the three fractures obtained by carrying out the test as described in paragraph 24.

12. *Percussive Test.*—This test is only specified for large steel castings. It consists in suspending and hammering the casting at numerous places. The test is made to locate any cracks, flaws, defects, or weakness in the casting.

E. THE TEST-PIECES AND METHODS OF TESTING SPECIFIED.

13. *Tensile Specimens.*—The standard turned test specimen, half an inch diameter and 2-inch gauged length (see Fig. 1) is prescribed in the specifications for steel castings, axles, forgings, and tires.

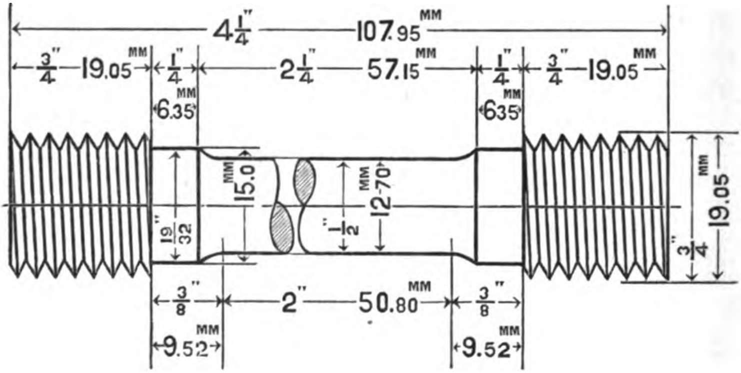


FIG. 1.

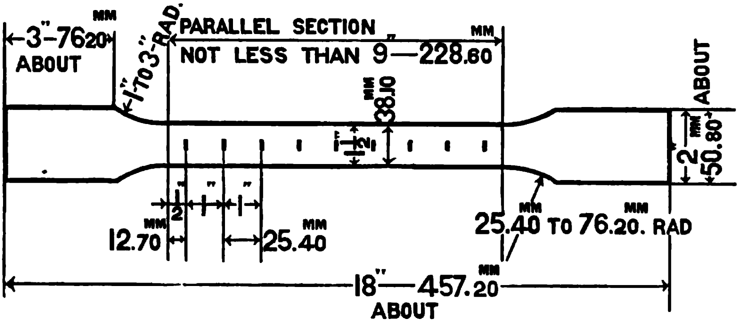
Much may be said in favour of the general adoption of this test specimen of a gauged length of four diameters for the commercial testing of these four classes of steel. With axles and all steel forgings a much shorter prolongation of the forging is required for a longitudinal specimen of the above length than for a test specimen of 8-inch gauged length. The shorter specimen therefore requires the manufacturer to consign much less good metal to scrap, an item of considerable importance to the customer in the case of forgings of large diameters.

Furthermore, less time and labour is expended in cutting out and machining the shorter test specimen. At a given cost a much better idea of the quality of the metal can therefore be obtained, for several short specimens can be taken at different positions in an important casting or forging at the same cost for preparation as one long specimen.

The shorter specimen has also the great advantage of enabling the customer to determine the character of the material at places in a complicated casting or forging where there is not space enough for a longer specimen, as between the webs of crank shafts. In the case of steel tires the shorter specimen is greatly preferable, for when cut from the rim of the tire used for the drop test, the longer specimen can very seldom be obtained unless the tire is heated and straightened, an operation which at once destroys its value as a representative test of the finished tires of the melt.

Finally, the physical properties called for in the specifications for steel castings, axles, forgings, and tires can be accurately and readily determined when using the standard test specimen recommended; for in cases where elastic limit is specified instead of yield point, an apparatus reading to the one ten-thousandth of an inch (0·0001") can be easily attached and readings readily made. The determination of the tensile strength is not materially affected by the length of the specimen. The percentage of contraction of area and the quality of the fracture, both very important factors in determining the quality of the metal, are shown with equal accuracy and distinctness with the shorter specimen as with one of greater length. The higher percentages of elongation obtained on two inches are compensated for by having correspondingly higher requirements in the specifications. There are therefore no practical objections to the general adoption of the test specimen shown in Fig. 1 for the commercial testing of these four classes of materials.

For the sheared plates used in structural steel for buildings, structural steel for bridges and ships, and in open-hearth plate steel, the specifications call for the standard test specimen of 8-inch gauged length shown in Fig. 2. For material other than sheared plates these three specifications provide that the test specimen may be that shown in Fig. 2, or it may be planed or turned parallel throughout its entire length, and in all cases where possible two opposite sides of the test specimen shall be the rolled surfaces. The three specifications further provide that rivet rounds and small rolled bars shall be tested of full size as rolled. In the specification for splice bars it is not specified whether the test specimen shall be planed parallel or of the shape shown in Fig. 2. Owing to the shape of the section of splice bars the parallel specimen can be more readily obtained. In all these necessary variations from the shape of specimen shown in Fig. 2, however, the same gauged length of 8 inches is required.



PIECE TO BE OF SAME THICKNESS AS THE PLATE.

Fig. 2.

The standard test specimen shown in Fig. 2 has already been so generally adopted for the commercial testing of all kinds of sheared plates that argument in its favour is almost superfluous. In the present day of large products of structural and plate steel, the preparation of the many test specimens, without a delay in shipment of finished material, necessitates the adoption of a standard sized specimen which can be readily prepared in groups, by special machines, from the coupons from plates of varying thicknesses. The ability to compare the physical properties of different makes of such a wide variety of steel, made possible by the use of the standard test specimen, forms the strongest argument in favour of its general adoption.

14. *Number of Tensile Specimens.*—In the specifications for driving axles, tires, structural steel for buildings, structural steel for bridges and ships, and splice bars, one tensile specimen from

each melt or blow, as the case may be, is recommended. With open-hearth plate and rivet steel one specimen is taken from each plate as rolled, and two from each melt of rivet rounds. The specifications for castings and for forgings state that the number of tensile specimens shall depend upon the character and importance of the casting or forging, and must therefore be regulated by individual cases.

15. *Location of Tensile Specimens.*—The specifications for structural steel for buildings, structural steel for bridges and ships, open-hearth plate and rivet steel, and splice bars, contain no instructions as to the location of the tensile specimen. For driving axles and forgings it is provided that the tensile specimen shall be cut longitudinally, and that the centre of the specimen shall be half-way between the centre and outside of the axle or forging. When forgings have large ends or collars, the test specimen shall be taken from the prolongation of the same diameter or section as that of the forging back of the large end or collar. In the case of hollow shafting, either forged hollow or bored, the specimen shall be taken within the finished section prolonged half-way between the inner and outer surface of the wall of the forgings.

With steel castings it is specified that the tensile specimen shall be cut cold from a coupon to be moulded and cast on some portion of one or more castings from each melt or blow, or from the sink heads (in case heads of sufficient size are used). With steel tires the specimen shall be cut cold from the tire tested under the drop, or if no drop test is required, the test specimen shall be forged from a test ingot cast when pouring the melt; the test ingot receiving, as nearly as possible, the same proportion of reduction as the ingots from which the tires are made.

16. *Annealing of Tensile Specimens.*—The specification for steel castings states that the coupon or sink head must receive the same treatment as the casting or castings before the specimen is cut out, and before the coupon or sink head is removed from the casting. The specifications for structural steel for buildings and for structural steel for bridges and ships both provide that material which is to be used without annealing or further treatment shall be tested for tensile strength in the condition in which it comes from the rolls; whereas with

material which is to be annealed or otherwise treated before use, a full-sized section of tensile test specimen length shall be similarly treated before cutting the tensile test specimen therefrom.

17. *Methods for Tensile Tests.*—None of the specifications prescribe the methods to be used for the determination of tensile strength, elongation, or contraction of area. All of the specifications in which the yield point is included in the prescribed physical properties state that the yield point shall be determined by the careful observation of the drop of the beam or halt in the gauge of the testing machine. In the specification for steel forgings, where elastic limit is required in some cases, it is provided that the elastic limit specified shall be determined by means of an extensometer, which is to be attached to the test specimen in such manner as to show the change in rate of extension under uniform rate of loading, and will be taken at that point where the proportionality changes.

18. *Test Specimens for Bending.*—As stated in paragraph 9, no bending test is included in the specifications for axles, tires, and rails. It was considered unnecessary to specify the length of the bending specimen in any case. For castings and forgings, a specimen one inch wide by half an inch thick is specified. With structural steel for buildings and for bridges and ships, and with open-hearth plate and rivet steel, it is specified that the bending specimen shall be 1½ inches wide if possible; and further, that with material three-quarters of an inch and less in thickness the specimen shall have the natural rolled surface on two opposite sides, whereas in case of material more than three-quarters of an inch in thickness the specimen may be half an inch thick. Each of these three specifications state that bending tests on rivet rounds shall be made on full-sized specimens, as rolled. With splice bars no particular size is specified when the specimen is cut from the head of the splice bar. If preferred, the bending test may be made on an unpunched splice bar, which, if necessary, shall be flattened before testing.

19. *Number of Bending Test Specimens.*—The specifications for structural steel for buildings and for bridges and ships and for splice bars specify that one bending test specimen shall be

taken from each melt or blow. For open-hearth plate and rivet steel, one cold bending specimen, and one quenched bending specimen will be furnished from each plate as rolled, and for rivet rounds two cold bending specimens, and two quenched bending specimens from each melt. The specifications for castings and forgings state that the number of bending tests will depend upon the character and importance of the casting or forging.

20. *Location of Bending Test Specimens.*—No special location for the bending test specimen is mentioned in the specifications for structural steel for buildings, for bridges and ships, and for open-hearth plate and rivet steel. For splice bars the specimen may be cut from the head of the splice bar, or, if preferred, the bending test may be made on an unpunched splice bar, which, if necessary, shall be flattened before testing. When forgings have large ends or collars, the bending test specimen shall be taken from a prolongation of the same diameter or section as that of the forging back of the large end or collar. In the case of hollow shafting, either forged, hollow, or bored, the specimen shall be taken within the finished section prolonged, half way between the inner and outer surface of the wall of the forging. With steel castings, it is specified that the bending test specimen shall be cut cold from a coupon to be moulded and cast on some portion of one or more castings from each melt or blow, or from the sink heads (in case heads of sufficient size are used).

21. *Annealing of Bending Test Specimens.*—The specification for steel castings states that a coupon or sink head must receive the same treatment as the casting or castings before the bending test specimen is cut out and before the coupon or sink head is removed from the casting. With forgings the bending test is cut from a prolongation of the finished and treated forging. With splice bars, structural steel for buildings and for bridges and ships, and with open-hearth plate and rivet steel, it is specified that the bending test specimen shall be taken from the material as it comes from the rolls, even if the material is to be subsequently annealed, which is the case with eye-bars.

22. *Methods for Bending Tests.*—Each of the six steel specifications in which a bending test is required contains the following clause: "The bending test may be made by pressure or by blows."

23. *Methods for Drop Tests.*—The drop tests required for axles, tires, rails, and castings are noted in paragraph 10. In each case a sample of the finished material ready for shipment is subjected to the test; in the case of rails it is specified that the piece tested shall not be more than 6 feet long. In testing axles and tires one is selected from each melt. In testing rails, a piece of rail is selected from every fifth blow, with provision for testing intermediate blows in case three rails from the tested blow fail. In steel castings where the drop test or test to destruction, as it is called, is substituted for the tensile test, three castings from a lot are tested, the lot consisting of all the castings from the same melt or blow annealed in the same furnace charge.

Tires are placed vertically under the drop in a running position on a solid foundation of at least ten gross tons in weight and subjected to successive blows from a tup weighing 2240 pounds, falling from increasing heights until the required deflection is obtained. Rails are placed head upwards on solid supports three feet apart. It is specified that the anvil block shall weigh at least 20,000 pounds, and that the supports shall be a part of, or firmly secured to, the anvil. Also that the tup shall weigh 2000 pounds, and that its striking face shall have a radius of not more than 5 inches. The machines in use in America vary somewhat in other non-essential details.

Axles are placed on supports 3 feet apart in such a position that the tup will strike the axle midway between the ends. The anvil must weigh 17,500 pounds and the tup 1640 pounds; the radius of supports and of the striking face of the tup in the direction of the axis of the axle must be 5 inches. The anvil is supported on twelve helical springs, which rest on a cast iron base resting in turn upon a solid foundation. The anvil must be free to move in a vertical direction. Each of the twelve springs has an outside diameter of 8 inches, and consists of five coils of a rod 1–$\frac{3}{16}$ inch diameter and seven coils of a rod $\frac{13}{16}$ inch diameter. The free height of the spring is 1–$\frac{1}{8}$ inch, and height under a load of 6650 pounds, 7 inches. This axle-testing machine is in general use in America for testing axles, and is recommended by the Master Car Builders' Association of the United States. The specification for axles gives full details of the method by which the required deflections for the different sized axles shall be measured.

24. *Method for Homogeneity Test.*—A portion of the broken tensile specimen is used for making the homogeneity test required on fire-box steel. Three transverse grooves about one-sixteenth of an inch deep are made in the steel either by nicking with a chisel or by means of a machine. The first groove is 2 inches from the square end of the specimen, the second 2 inches from it on the opposite side, and the third 2 inches from the second groove on the opposite side from it. The test is made by fastening the specimen in the vice firmly with the first groove about a quarter of an inch above the jaws, and bending it away from the first groove by a number of light blows from a hand-hammer until it breaks. It is broken at the other two grooves in the same manner. The required freedom from flaws in these three fractures is described in paragraph 11.

25. *Method for Percussive Test.*—This test of large steel castings consists simply in suspending and hammering the casting at numerous places to locate the defects as outlined in paragraph 12.

26. *Samples for Chemical Analysis.*—Each of the nine steel specifications contains a paragraph defining the location of the drillings or turnings taken to determine whether or not the material conforms to the prescribed chemical requirements. The specifications for structural steel for buildings, structural steel for bridges and ships, steel splice bars, and steel rails, state that the drillings shall be taken from the small test ingot, cast while pouring the melt or blow. All the other specifications provide that the drillings may be taken from the small test ingot, if preferred by the inspector, but specify other locations as follows:—

In the case of castings and forgings, turnings from the tensile specimen or drillings from the bending test specimen may be used. With steel tires, turnings from the tensile specimen or from the tire itself may be used. With steel axles, turnings from the tensile specimen in the case of driving axles is recommended, and longitudinal drillings taken midway between centre and outside of the axle in the case of car, engine, and tender truck axles. The specification for open-hearth boiler plate and rivet steel provides, in the case of locomotive fire-box steel, that a check on the analysis of the small test ingot may be made from drillings from the tensile specimen from each plate as rolled; and for other material, from drillings from one tensile specimen from each melt.

In the case of steel rails, splice bars, and the structural steel for buildings, bridges, and ships, it is proper to limit the analyses to drillings from the test ingot taken when pouring the heat, for a representative average sample of each melt or blow cannot in these cases be taken in any other way. No one who has studied the unavoidable variations in chemical composition of the different parts of a section of a rail—for instance, the bottom of the flange, the top of the head, and the centre of the head—will claim that the analysis of drillings from a rail is representative of the heat from which the rail was rolled. Furthermore, even with a proper percentage of discard, there is a variation in chemical composition between the rail from the top and from the bottom of the same ingot. These same statements are true of splice bars and of the structural steels.

Even with the test ingot it is necessary to exercise care to avoid segregation and obtain a representative average sample. Whenever the steel shows a decided tendency to rise in the small test ingot moulds, it is advisable to quiet it by adding a very minute quantity of pure metallic aluminium, for otherwise drillings taken for carbon determination in the vicinity of the blowholes will give misleading results. It is also advisable to roll or hammer the test ingot into a bar, and drill a hole through the bar, rather than to obtain the drillings for analysis from the test ingot itself. With these precautions the test ingot may be relied on to furnish a representative average sample of the melt or blow of steel.

27. *Methods for Chemical Analysis.*—All suggestions as to methods for chemical analysis have been purposely omitted from the specifications under discussion. Entire uniformity in the details of the various analytical methods used in steelworks laboratories will probably never be realised, nor is it a necessity in obtaining accurate chemical analyses.*

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* The reader is referred to the excellent paper by the Baron Hanns Jüptner von Jonstorff entitled "The Introduction of Standard Methods of Analysis." *Journal of the Iron and Steel Institute,* No. I., 1896, pp. 80–138.

Great credit should be given to the steelworks chemist for the success which has attended his earnest efforts to meet the urgent demands made on him for rapid accurate analyses, for he has thereby very materially assisted the steelmaker in securing and maintaining uniformity in his product.

F. Variation in Weight.

28. The variation in weight permissible in rolling plates is very properly included in the specifications for structural steel for buildings, structural steel for bridges and ships, and open-hearth plate and rivet steel. The overweight is caused by the unavoidable wear of the plate rolls, usually producing a plate slightly thicker in the central part than on the edges. A prescribed standard of excellence in this regard places all manufacturers on equal footing, and requires them to keep their plate rolls in good condition. The allowances are based on the assumption that one cubic inch of steel weighs 0·2833 pound, and provision is made for plates ordered by weight, and also when ordered to gauge. The prescribed variations are very properly the same in each of the three specifications.

G. Finish.

29. Such a wide variety of finished material is covered in the nine steel specifications under discussion, that a summary of the clauses contained under this heading is impossible. In each case the requirements are drawn so that only material with a workmanlike finish and freedom from injurious imperfections shall be accepted. In the specification for rails the question of finish is treated under the subdivisions "Section," "Weight," "Length," "Drilling," and "Finish." Second quality of No. 2 rails is also defined.

H. Branding.

30. The marking of finished material is now in general use. It permits the identification and date of manufacture of material which has given exceptionally good or long service, or which has failed in service, and is thus a protection and an advertisement

for the reputable manufacturer. A review under this heading of the nine steel specifications shows that, in all cases but castings and forgings, every finished piece must be marked, except that small pieces may be shipped in bundles securely wired together, with the melt or blow number on a metal tag attached. In the case of rails, besides stamping the blow number of each rail, the name of maker, the month and year of manufacture, must be rolled in raised letters on the side of the web of each rail. In splice bars the name of maker and the year of manufacture must be rolled in raised letters on each side of the splice bar. In axles, besides the melt number the initials of the maker must be stamped on each axle; and in tires the maker's brand and number must be stamped on each finished tire.

I. INSPECTION.

31. Each specification makes ample provision to insure the inspector all facilities necessary for a thorough inspection of the material.

DISCUSSION.

Dr. Charles B. Dudley (Chemist to the Pennsylvania Railroad Company) said they were recognising more and more the necessity of studying the conditions under which the metal did its work, in order to know how to test the material that would meet the required conditions. The subject was a very big one. There was a good deal of discussion in America, which extended over some years, over a little work which he did on steel rails; and he wished to say now that he thought both he himself and all those who discussed his papers missed the real key to the situation. The thought had dawned upon him something like this: They tried to find out what metal would wear best in rails and what would give the greatest safety. Leaving the latter part of the subject for the moment, he would deal with the question, What metal gave them the best resistance to wear? They had missed one of the real points of the situation, viz., the cold-rolling action of the wheels on the top of the rail. Subsequent to his published work on steel rails some bars of steel were cold-rolled at some works at Pittsburgh, the two classes chosen being very hard and very soft rail steels. After these had been cold-rolled, and reduced in size a little by cold-rolling, they were tested physically. As they all knew, cold-rolling increased the tensile strength and diminished the elongation. Singularly, the change was greatest in the hard steels; in other words, a hard steel of 80,000 lbs. tensile strength would be increased from twenty to twenty-five thousand by cold-rolling. A soft steel of sixty-thousand would only be increased ten-thousand by cold-rolling. Experiments had been made at Watertown Arsenal on rails that had done service. The rail was bent. It was found that the bending would only take place a short distance before the rail would crack. Then the skin was planed off from the top portion of the same rail. When this skin (which had had the cold-rolling action of the wheels) was removed, it would be possible almost to bend the rail double without breaking. The application of this was that the nature of the metal was changed by the action of the drivers making it more brittle, and consequently wearing more rapidly. In regard to testing material, they found in a large number of places where material was used that they had alternate transverse strains. The axle, for example, was subjected to alternate transverse strains every time that it revolved. They were finding out that certain kinds of steel did not stand these strains. Some years ago they began to use axles as in the English practice, containing twenty to twenty-five hundredths of carbon. In a short time the journals began to drop off from those axles, and the matter became serious. When it came to them after it dropped off, there was an irregular portion of fresh break, the rest, being old, having broken off in detail from time to time. Many of these sections were more one-sided than others, but all had the detailed fracture. As a leap in the dark, they simply increased the tensile strength by 20,000 lbs. They were using 60,000 lbs. steel, and they jumped to 80,000 lbs., and their difficulty disappeared. The conditions under which the metal did its work must decide how they tested. He recognised the value of tensile test, elongation, and the contraction of area; but they had still to go further, and such papers as Mr. Colby's, showing what had been done and what could be done, were steps in the advancement of their knowledge.

Mr. R. A. **Hadfield**, Member of Council, was much indebted to Mr. Colby for his paper. He wished to refer to that part dealt with by the author regarding the chemical properties which were to be specified in the steel according to standards decided upon. There were nine standard specifications under discussion, and where tensile strength was specified, limits in carbon had been purposely omitted except in the case of splice bars. Limits in manganese were included for tyres, boiler-plate, rivet steel, splice bars, and rails; and silicon only in case of tires and rails. The author had explained, however, that "phosphorus is very properly specified in all the different classes included in the nine steel specifications, and sulphur in all but rail steel and structural steel for building." Mr. Hadfield did not agree with these views. He was of opinion that chemical analyses should be a matter for the steelmaker, and should not enter into the engineer's specification. It was for the latter to impose the conditions which the steel should fulfil, and the maker should be at liberty to get the results as he best could, so that the material would do the work required from it. As it was, steelmakers were often subjected to great hardship. An exact proportion of some alloy would be specified, and if analysis came out the smallest degree in excess, the steel would be rejected, however well it would comply with all the conditions of work laid down. Rejections were made on extremely fine points of chemical analysis which could not affect the engineer, and he was of opinion that the exact contents of sulphur or phosphorus should be left to the steelmaker, the engineer laying down the conditions of work the metal should be able to stand.

Mr. A. Greiner, Member of Council, pointed out that last July Mr. Colby had read before the meeting of the International Association for Testing Materials, held in Paris, a similar paper, and it was discussed for three hours under his own presidency; and it would be of great interest to the members of the Institute to read the full discussion which took place at that time on this interesting paper.

Mr. E. P. Martin, Past-president, said that certain remarks which fell from Mr. Dudley had been verified by the experiments of the recent Government Committee on steel rails, especially that point referring to the question of the hardening of the wearing surface of the rail. He looked upon that question very much in this way: that in the process of drawing wire they hardened the surface which was made again soft and malleable by annealing. The strength of a worn rail could be restored in the same way, or by removing the thin hardened portion of the rail. As to the question of axle-breaking, he might say that they had a disappointing experience in their mines by using steel axles, and for a time they could not understand why they had so many breakages. After looking very carefully into the matter, the cause of the trouble was removed by simply causing the shoulder to be rounded instead of being cut square. A very large number of breakages of steel were due to the fact that the form of the material was too suddenly changed.

The PRESIDENT said the Commission on steel rails, on which Mr. Martin and himself both sat, had issued their Report, and the St. Neots rail, which was the basis of the inquiry, contained local patches of martensite; but the Commission had not been able to explain satisfactorily the presence of this particular form of carburised iron. All the other points had been fully borne out by Mr. Colby's observations. What he (the President) thought was important in the case of steel rails was to know what had been their previous thermal treatment, the exact temperature at which the rolling had been performed—in fact, to know their life-history before they became rails. The St. Neots rail was an admirable one as regarded analysis. It might almost have formed a typical basis for specifications, and yet it was broken like glass into eighteen pieces, and not after a prolonged use; and then there was the presence of martensite. There were, he should not omit to say, the results of beautiful experiments in the Swedish Section of the Exhibition, by Mr. Brinell, and he strongly recommended the members to see them because they were of very great interest.

Mr. COLBY, in reply, said that there was one point made in the discussion to which he would like to reply. He referred to Mr. Hadfield's criticism that all chemical requirements should be omitted from specifications, and the manufacturer left free to select his steel, meeting the physical requirements specified. This same position was taken by French and German engineers who had participated in the long discussion of his (Mr. Colby's) paper on this subject, read at the International Congress on Testing Materials of Construction, held in Paris last July, and which discussion Mr. Greiner had just recommended the members of the Institute to read. Personally, he (Mr. Colby) was of the same opinion as Mr. Hadfield, for in his own experience, as Metallurgical Engineer of the Bethlehem Steel Company, he had often seen unnecessary hardships placed on the manufacturer by the strict adherence to definite limits in sulphur and phosphorus, and the rejection of steel because, perhaps, it contained 0·005 per cent. more sulphur than the limit specified. He would like to explain that these proposed American standard specifications were the result of a compromise, as they represented the recommendations of the American Branch of Committee No. 1 of the International Association for Testing Material, which Committee consisted of thirty-four members, seventeen of them being consulting and inspecting engineers, or else representatives of large consumers of steel, and seventeen engineers or metallurgists connected with the large steel manufacturers of America. As all the members of the Committee were impressed with the many practical advantages resulting, if standard specifications could be arrived at, concessions were made on both sides, particularly on the part of the manufacturers, who were desirous not to have the recommendations of the Committee subsequently criticised as manufacturers' specifications. The paper which he read at the French Congress last July contained the full text of the ten proposed American standard specifications. He had had a large edition of this paper printed in English, as well as in French and German, and would be very glad to send a copy to any one interested in the subject.

CORRESPONDENCE.

Mr. C. P. **Sandberg**, called upon by the President, said that he had very little to add to the rail question discussion that had taken place at the Institute's meeting in Stockholm on his paper, "On the Danger of Using too Hard Steel Rails." The experience of the last severe winter in Sweden had strengthened his views of using a steel of medium hardness for rails as most suitable for that country.

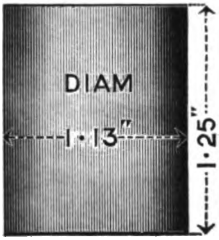
Mr. Sandberg has, however, since added in writing his observations on the rail question at the Railway Congress held in Paris at the same time. The question of rail steel was there discussed as to its hardness, America being represented by Mr. P. H. Dudley of New York Central, who advocated hard steel, and Dr. C. B. Dudley of Pennsylvania, who was in favour of soft steel, and both had their supporters, but no definite decision was fixed by the Congress as to which was the most durable. Mr. Post, of the Dutch State Railways, as reporter for Holland and Germany, stated that after twenty years' study he was undecided as to which steel was the best, for although the soft rails wore faster in the beginning, say after 30,000 trains' passage, the hard rails were worn as much as the soft ones after 90,000 trains' passage. So he left it an open question. As for breakages, very few statistics were given from America, except that the rails break mostly at a cold temperature. Russia had a very large number of fractures. Sweden can be proud of its results in this respect, being in about the same position as England notwithstanding its severe climate. But the rails have always been kept on the soft side, or say about 0·42 per cent. carbon, with a maximum of phosphorus of 0·075 per cent. However, the Swedish Railway Administration had in 1898 been tempted by the American papers to increase the carbon up to 0·50 per cent., but found their rail fractures increased during last winter, so they have returned to their former hardness of 0·42 per cent., preferring to keep on the safe side; and at the same time they have increased their falling test by 10 per cent., since they found that rails breaking on the road during winter would stand in summer the specified test of a 1-ton ball falling 20 feet. As a proof of good wearing results from rails of a medium hardness, it may be mentioned that the Goliath rail, with a carbon of 0·43 per cent., laid down at Barrow ten years ago, under very heavy traffic, has only worn 3 mm., and is still wearing well. But rails have another function, namely, to withstand crushing, particularly at the ends, and in this respect there is no doubt that the hard steel would be preferable. As the President referred to Mr. Brinell's mode of testing in the Swedish Exhibition, he (Mr. Sandberg) might here mention that he used a similar mode in 1894, with a view to applying the same to rail inspection. See table of results herewith obtained from the crushing tests of sample steel of different hardness—0·40, 0·50, and 0·60 per cent. carbon, from three different makers. As shown by this table, the 0·60 per cent. carbon steel would stand twice as much load as 0·40 per cent. carbon did for the same compression, but this must not lead us to employ harder rails than will stand the traffic without breaking. The flattening of the rail ends is certainly a very costly matter, and often makes it necessary to renew rails before they are worn out, but this can to a great extent be remedied by better joints and better ballast, and only such rails should be used that are safe against fractures—in fact, safety before all.

Crushing Tests.

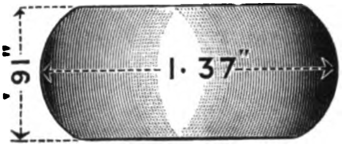
Samples of Rail Steel made at three different English Hæmatite Steelworks.

Original sizes of pieces 1·25 inch long by 1·13 inch diameter = area, 1 square inch.

Before testing.



After testing.



Dead Load Tons per Square Inch.	Increase of Diameter in Inches.								
	Works A. Carbon.			Works B. Carbon.			Works C. Carbon.		
	0·40 per Cent.	0·50 per Cent.	0·60 per Cent.	0·40 per Cent.	0·48 per Cent.	0·60 per Cent.	0·40 per Cent.	0·50 per Cent.	0·60 per Cent.
40	0 02	0·01	0·01	0·03	0·02	0·01	0·04	0·01	0·02
50	0·05	0·04	0·03	0·07	0·04	0·02	0·10	0·02	0·03
60	0·10	0·07	0·05	0·13	0·08	0·04	0·17	0·04	0·04
70	0·17	0·13	0·07	0·18	0·14	0·07	0·26	0·09	0·09
80	0·24	0·20	0·13	0·23	0·21	0·12	0·32	0·16	0·16
Tons required for first set . .	25·6	30·00	34·00	24·6	28·6	31·6	24·6	31·00	32·5
Diminished length after crushing .	0·34	0·29	0·17	0·33	0·28	0·17	0·45	0·22	0·21

Average Chemical Composition with Carbon per cent. as above.

	Per Cent.	Per Cent.	Per Cent.
Silicon	0·090	0·085	0·060
Phosphorus . .	0·065	0·055	0·060
Manganese . .	1·000	1·000	0·950

On the motion of the President, a hearty vote of thanks was given to Mr. Colby for his paper, and the following paper was then read:—

THE INFLUENCE OF ALUMINIUM ON THE CARBON IN CAST IRON.

BY GODFREY MELLAND, B.Sc. (VICT.), ASSOC.R.S.M., AND HARRY W. WALDRON, BOWEN SCHOLAR IN METALLURGY AT THE MASON UNIVERSITY COLLEGE, BIRMINGHAM.

THE action of aluminium in causing the separation of graphite when added to cast iron containing carbide has been studied by W. J. Keep * in America, and more recently in this country by T. W. Hogg. †

Keep, looking at the question from the point of view of the practical foundryman, studied mainly the changes in the mechanical properties of white or hard grey irons, which are produced by the addition of definite amounts of aluminium to them when in the molten condition. In a later paper ‡ he gives analyses of the treated metals. He found that a white iron became distinctly grey after the addition of 0·75 per cent. of aluminium, but that the amount of graphite separated and the softening of the metal increased up to 4 per cent. of that metal. He also noted that cast iron containing aluminium remained graphitic when cast in a chill mould.

In making a comparison between the action of silicon and aluminium upon the carbon in cast iron, he states that the metal when added in large amounts has the property, also possessed by silicon, of causing a reduction in the total carbon of the iron.

This last statement is not confirmed by the experiments of T. W. Hogg, which show that the total carbon remained practi-

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* *Journal of the Franklin Institute*, vol. cxxvi. pp. 220-231.

† *Journal of the Iron and Steel Institute*, 1894, No. II. p. 104.

‡ *Transactions of the American Institute of Mining Engineers*, vol. xviii. p. 102.

cally constant with varying amounts of aluminium up to 12 per cent. He also found that with white and grey Swedish iron practically the whole of the carbon was set free as graphite on the addition of 1 per cent. of aluminium (the smallest amount used in his experiments), whether the metal were cooled quickly or slowly. With 4 per cent. of aluminium the amount of graphite fell somewhat, and with 12 per cent. practically the whole of the carbon was found to be again in the combined state.

The metals made use of by these investigators were not very pure; they contained notable amounts of silicon (from 0·5 to 0·75 per cent.). Keep, moreover, added his aluminium in the form of ferro-aluminium, containing 11·42 per cent. aluminium and 3·86 per cent. of silicon. The considerable amount of this element present in both cases makes it rather doubtful whether the effects produced upon the metals can be attributed entirely to the added aluminium.

A. Borsig[*] has given one analysis which shows that there is a considerable separation of graphite with only 0·16 per cent. of aluminium present in the metal, but up to the present time no work has been published giving in a systematic manner the exact influence of quantities of this metal less than 1 per cent. upon the condition of the carbon in white cast irons.

In the present research we have endeavoured—(1) to determine the amount of aluminium which is necessary to produce the maximum separation of graphite in a white iron as free as possible from silicon and other impurities; (2) by casting every melting both in sand and chill moulds, to ascertain the effect produced by slow and rapid cooling upon the mode of existence of the carbon in the metal with varying amounts of aluminium from 0·02 per cent. up to 12 per cent.

METHOD OF MAKING THE ALLOYS.

The metal selected as a basis for the experiments was a white Swedish charcoal pig iron, of which the analyses below show the composition:—

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[*] *Journal of the Iron and Steel Institute*, 1894, No. I. p. 529.

	Original Pig.	Remelted.	
		Slowly Cooled.	Rapidly Cooled.
Total carbon	3·9	3·98	3·98
Graphite	0·38	0·76	0·48
Combined carbon (by diff.) . .	3·52	3·22	3·50
Silicon	0·24	0·28	0·28
Manganese	0·09	0·087	0·089
Sulphur	0·032	0·032	0·033
Phosphorus	0·066	0·065	0·065

The aluminium used was the best commercial metal made by the British Aluminium Company, and contained only about 1 per cent. of impurity, which consisted mainly of iron.

The meltings were made in fireclay crucibles heavily brasqued with powdered charcoal to prevent any possible increase in the amount of silicon from contact of the metal with the pot, and also to prevent excessive oxidation. The above analyses of the original metal show that it suffered practically no alteration in composition by the remelting.

The amount of metal used for each melting was between 3 and 4 lbs.

In the first few meltings the aluminium was placed at the bottom of the crucible, covered with a little powdered charcoal, and the pig iron was placed on the top. The whole was then melted down in the wind furnace, well stirred with an iron rod, and then poured. The subsequent analyses of these specimens showed that they contained in most cases the merest trace of aluminium. Investigation of the crucibles showed that the greater part of the aluminium was still adhering to the brasquing at the bottom, and had not passed into the iron at all, the thin layer of charcoal with which they were covered being sufficient to keep the two metals out of intimate contact with each other.

In the later experiments the aluminium was melted separately in a crucible, either alone or under coverings of fluor spar or charcoal, and the molten iron was poured into it, the whole being well stirred as before. The best results were obtained when no charcoal or flux was employed in the melting.

Loss of Aluminium.—In making the alloys containing small amounts of aluminium, the quantities of this metal found in the iron varied considerably and the loss was generally great. As little as 2 or 3 per cent. of the aluminium added was found in the metal from some of the earlier castings.

The best result obtained when the aluminium added was under 1 per cent. was that of the metal which retained 0·438 per cent. out of 0·6 added, the loss in this case being only 27 per cent.

In the richer alloys, however, the results were much more satisfactory. With 1 per cent. and upwards of aluminium the amount retained was generally over 30 per cent., and, in one case (No. 31, Table I.), as much as 90 per cent. of the amount added. These good results were only obtained when the second method of making the alloys was employed. The loss was, of course, due to oxidation, partly by oxide of iron formed during the melting of the metal, and partly by the aluminium rising to the top of the metal and being oxidised on the surface by the air. The surfaces of many of the castings were covered with a thin film of alumina.

Method of Casting.—At least two specimens were cast from each melting, one rapidly cooled and the other slowly cooled. In addition to these, castings were also taken in a few cases for compression tests. The rapidly cooled samples were cast in an open cast iron chill mould, considerably heavier than the casting to be made.

The slowly cooled samples were cast in a small compressed carbon mould, previously heated to redness, which was embedded in dry sand, and, after the metal was cast, was completely covered with a thick layer of the same material. Cast in this way, a mass of from 2 to 3 lbs. took several hours to become cool enough to be handled.

A summary of the analyses is given in the following table:—

TABLE I.

No.	Aluminium.	Silicon.	Total Carbon.	Graphite.		Relative Density at 20° C.
				Rapidly Cooled.	Slowly Cooled.	Slowly Cooled.
1	Original pig. (None.)	0·24	3·90	0·38	0·38	...
2	Pig remelted. (None.)	0·28	3·98	0·48	0·76	7·64
3	trace	0·27	3·96	0·52	0·78	...
4	trace (0·002)	0·25	3·94	0·43	1·06	...
5	0·003	0·22	3·98	0·36	1·2	...
6	0·023	0·23	...	0·55	2·32	...
7	0·024	0·23	3·93	0·30	1·20	7·58
8	0·026	0·27	4·07	0·50	1·87	...
9	0·058	0·28	...	0·50	1·73	...
10	0·114	0·22	...	0·54	2·64	...
11	0·160	0·21	4·00	0·32	3·01	...
12	0·179	0·22	...	0·41	2·50	...
13	0·180	0·20	3·90	0·57	1·55	...
14	0·185	0·20	...	0·55	2·8	...
15	0·232	0·22	3·91	0·59	3·15	...
16	0·250	0·19	3·96	0·91	3·49	...
17	0·325	0·19	...	0·92	2·91	...
18	0·389	0·20	...	1·51	2·96	...
19	0·438	0·25	3·95	1·36	3·35	...
20	0·527	0·21	3·83	3·06	2·93	7·12
21	0·566	0·21	...	2·91	3·37	7·11
22	0·722	0·21	3·96	2·64	2·92	...
23	1·239	0·21	4·08	2·95	2·97	...
24	1·246	0·23	...	2·81	2·87	...
25	1·25	0·29	...	2·91	3·01	...
26	1·78	0·28	4·07	2·96	2·93	7·11
27	2·375	0·19	3·76	2·73	2·60	...
28	3·82	0·22	3·59	2·53	2·54	...
29	4·24	...	3·57	2·28	2·49	6·88
30	8·31	...	3·32	0·66	0·99	6·53
31	11·80	0·26	3·12	0·20	0·20	6·69

Remarks on the Analyses.—The analyses have in every case been carefully checked, and in doubtful specimens as many as three concordant results have been obtained. The method used for the estimation of the aluminium was the one described by J. E. Stead [*] in the *Journal of the Society of Chemical Industry*, vol. viii. p. 965, slightly modified to suit our requirements.

[*] Briefly, the method consists in adding to the solution of the mixed chlorides of the two metals a certain amount of sodium phosphate (varying with the amount of aluminium present), nearly neutralising and adding excess of sodium thiosulphate. This reduces most of the iron to the ferrous state and completely neutralises the hydrochloric acid, thus causing the precipitation of aluminium phosphate together with a small amount of ferric phosphate. This precipitate after filtering is redissolved and the iron completely precipitated by pure sodium hydrate. The aluminium is finally precipitated from the clear solution and weighed as the phosphate.

Effect of Aluminium on the Total Carbon.—An inspection of Table I. shows that the addition of aluminium in amounts less than 2 per cent. has no effect upon the total carbon of the metal. Beyond 2 per cent., however, there is a rapid decrease in the amount of carbon contained in the metal. To find the exact loss it is necessary of course to make a correction for the amount of aluminium which has been added. For instance, No. 31 would have contained 3·51 per cent. total carbon if none had been expelled, this being the amount of carbon originally contained in 100 – 11·8 = 88·2 parts of the remelted pig iron. The actual total carbon in this metal is 3·12, or a decrease of nearly 0·4 per cent. from the amount calculated.

Table II. shows the decrease in total carbon of the alloys containing more than 2 per cent. aluminium.

TABLE II.

No.	Per Cent. Aluminium.	Per Cent. Other Elements.	Actual Total Carbon.	Calculated Total Carbon.	Loss Total Carbon.
27	2·375	97·625	3·76	3·89	0·13
28	3·82	96·18	3·59	3·83	0·24
29	4·24	95·76	3·57	3·81	0·24
30	8·31	91·69	3·32	3·65	0·33
31	11·80	88·2	3·12	3·51	0·39

These results, while confirming the statement of Keep already referred to, are not in accordance with those found by Hogg, who obtained no decrease in the case of a white iron containing 0·45 per cent. of silicon, and a decrease of only 0·24 per cent. from the calculated amount, with about 12 per cent. of aluminium, when using a grey Swedish pig iron containing 0·75 per cent. of silicon.

Effect of Aluminium on the Separation of Carbon as Graphite.—It will be observed that in the quickly cooled specimens the aluminium effects practically no separation of graphite when less than 0·23 per cent. Above this there is a rapid increase, until with 0·527 of aluminium (No. 20) the graphite reaches its maximum amount of 3 per cent. This amount of graphite remains fairly constant up to 1·78 per cent. of aluminium (No. 26), after which there is a gradual decrease until with 11·8 per cent. of aluminium the metal contains even less graphite than the original pig iron.

In the case of the slowly cooled specimens the amount of graphite liberated is somewhat irregular where the added aluminium is low. Thus No. 6 contains much more graphite than it should, judging from the numbers immediately above and below it in the series, while in No. 13 the effect of 0·18 per cent. of aluminium is very small by comparison with that produced by 0·179 per cent. in No. 12.

It must be pointed out that these anomalous cases all occur in metal containing less than 0·3 per cent. of aluminium, *i.e.* they are metals in which the aluminium effects no separation of graphite in the chilled specimens. Although the different meltings were made as nearly as possible under the same conditions, the temperatures at which the metals were poured no doubt varied very considerably in different cases, and this would lead to a good deal of variation in the rate of cooling. With a metal which is quite white when chilled it is obvious that comparatively slight differences in the rate of cooling would cause great variation in the amount of graphite separated. It would be impossible, without special heating and casting appliances, and a careful measurement of the temperature of the metal when poured, to obtain sufficient uniformity in respect to the rate of cooling to prevent these anomalies.

When the amount of aluminium exceeds 0·3 per cent., and its effect of accentuating the critical point for graphite separation begins to be more marked, we do not meet with any more of these irregularities. With the aluminium from 0·23 to 1·78 per cent. the slowly cooled specimens are uniformly grey, and all contain about 3 per cent. of graphite. With larger amounts of aluminium the graphite diminishes (but more slowly than in the rapidly cooled metal), until with 11·8 per cent. there remains only 0·2 per cent. of graphite, and the rate of cooling has absolutely no effect.

The curves (Plate XIV.) show the effect of aluminium up to 0·6 per cent. upon the separation of graphite in both slowly and quickly cooled specimens. Considerations of space have prevented us from carrying them forward up to 12 per cent. of aluminium. It may, however, be said, that two curves run close together and almost horizontally up to 2·5 per cent. of aluminium and then fall gradually up to 12 per cent.

It is noteworthy that in no case is the whole of the carbon separated as graphite either in the quickly or the slowly cooled specimens, about 0·9 per cent. of carbon being generally retained in the combined form. In this respect the action of aluminium is much less powerful than silicon, as high silicon cast iron frequently contains no combined carbon. With regard to the effect produced by traces, however, the aluminium is much more powerful, as is shown by specimen No. 6, in which 0·023 per cent. of aluminium raises the percentage of graphite from 0·76 to 1·73 per cent. The maximum of graphite, moreover, is separated by less than 0·5 per cent. of aluminium, while the corresponding amount of silicon would cause practically no separation. We are not able to confirm the statement of W. J. Keep, already quoted, that the metal becomes softer and greyer up to 4 per cent. of aluminium. It seems probable that in his experiments, using ferro-aluminium rich in silicon, there might be a greater total separation of graphite, since in adding 4 per cent. of aluminium, 1·3 per cent. of silicon would also be added, which would be quite sufficient to set free as graphite the residual 0·9 per cent. of combined carbon which we always find.

The rate of cooling has practically no effect upon the percentage of graphite in the alloys containing from 0·527 to 4·24 per cent. of aluminium, and we are able to confirm Hogg's observation that the rapid cooling sometimes causes a slightly greater liberation of graphite than slow cooling.

Chilling of the Metal.—A reference to the table will show that the iron with 0·527 per cent. of aluminium contains about 3 per cent. of graphite, whether cooled slowly or rapidly, and this amount is not greatly increased by any further addition of aluminium. The quickly cooled specimen of No. 20, although in bulk containing actually more graphite than the slowly cooled one, was still quite white and hard for a thickness of about ⅛ of an inch from the surface of contact with the mould. All the quickly cooled specimens up to No. 25 show this thin layer of chilled metal, but No. 26 with 1·78 per cent. of aluminium shows no trace of whiteness, the metal being uniformly grey, even to the very edge of the fractured surface.

The rapidly cooled specimens, even when entirely grey, differ considerably in appearance from the corresponding slowly cooled specimens on account of the extreme fineness of their grain.

A few of the slowly cooled specimens in which the aluminium was low show a zone of grey metal extending about ¼ of an inch from the surface, the rest of the casting being either mottled or grey. Such specimens have been described before by J. W. Keep and R. A. Hadfield.* It seems not unlikely that this superficial greyness has arisen from the fact that those portions of the metal near the surface of the mould, under certain conditions as regards the temperature of pouring, would remain for a longer time within the critical range of temperature for graphite separation than the inner part, that part of the metal which first comes in contact with the mould, even when this is hot, and composed of a material which conducts heat badly, would immediately have its temperature very much reduced, and might pass through the critical range for carbon separation. Very soon, however, owing to the high temperature of the metal in the middle of the mould and to the bad conductivity of the mould, its temperature would rise and might pass again through the critical range. After a time it would, in the general cooling of the whole mass, pass through this range a third time. Under these conditions we might reasonably expect to find a greater separation of graphite near the surface of a small casting of metal, in which the tendency for this separation is not very decided, than in the central portion, where the critical temperature has been passed only once in the general cooling of the mass.

One of us having found that aluminium takes up carbon readily, forming the golden yellow carbide Al_4C_3, at temperatures lower than that at which white cast iron melts, it occurred to us as not unlikely that the reduction of graphite in the specimens with 8 to 12 per cent. of aluminium might be due to the formation of this carbide. It was found, however, that there was no evolution of hydrocarbons when the finely powdered metal was treated with water, even on heating. An examination of a polished and etched specimen of the metal containing 11·8 per cent. of aluminium, moreover, did not lead to the discovery of any of the characteristic states of this compound.

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* See *Journal of the Iron and Steel Institute*, 1894, No. II. p. 118.

Plate XV. shows (1) the original pig remelted and slowly cooled, and (2) the slowly cooled 11·8 per cent. metal magnified about 300 diameters. They show, as might be expected, a good deal of difference in structure. The area of cementite has become very much extended in the alloy, while the ferrite has so diminished as to be only represented by small areas showing a pearlitic structure and fine lines separating the crystals of cementite.

The large amount of apparently homogeneous cementite leads us to the conclusion that the mass of the metal consists of a double carbide of iron and aluminium having a lower carbon content than has Fe_3C.

Compression Tests.—A few compression tests were made with the object of ascertaining the softening effect produced by the addition of varying amounts of aluminium with the results tabulated below. It was found that the presence of 0·25 per cent. of aluminium reduced the resistance to crushing nearly 60 per cent. The metal, in fact, has the properties of a good soft foundry iron, and further additions of aluminium up to 3·8 per cent. do not increase the softness of the metal. The test-pieces were all slowly cooled with the exception of No. 22-A, which was cast in an iron mould. It is noteworthy that, although this specimen did not show the slightest sign of whiteness (the thin layer of white produced by chilling having been turned off before testing), and contained, in fact, almost exactly the same amount of graphite as the slowly cooled specimen, 22-B, it withstood a pressure of no less than 77 tons to the square inch, *i.e.* the compressive strength of the metal was increased by 35 per cent. by rapid cooling. The appearance of the specimen after fracture did not suggest that this increase in rigidity was effected at the expense of the toughness.

No.	Aluminium per Cent.	Crushing Load, Tons per Square Inch.
2	none	101·2
16	0·25	42·5
18	0·389	50·63
22-A	0·722	77·00
22-B	0·722	42·31
23	1·239	43·15
24	1·246	48·76
25	1·25	45·18
27	2·375	51·00
31	3·82	50·10

In conclusion we wish to express our indebtedness to Prof. Burstall for putting the testing machine of the Mason University College at our disposal for the purpose of these tests, and to Mr. F. Hummel for making the tests. Our thanks are also due to Mr. W. Macfarlane of the Wednesbury Technical School, who was good enough to take micro-photographs of some of our specimens.

DISCUSSION.

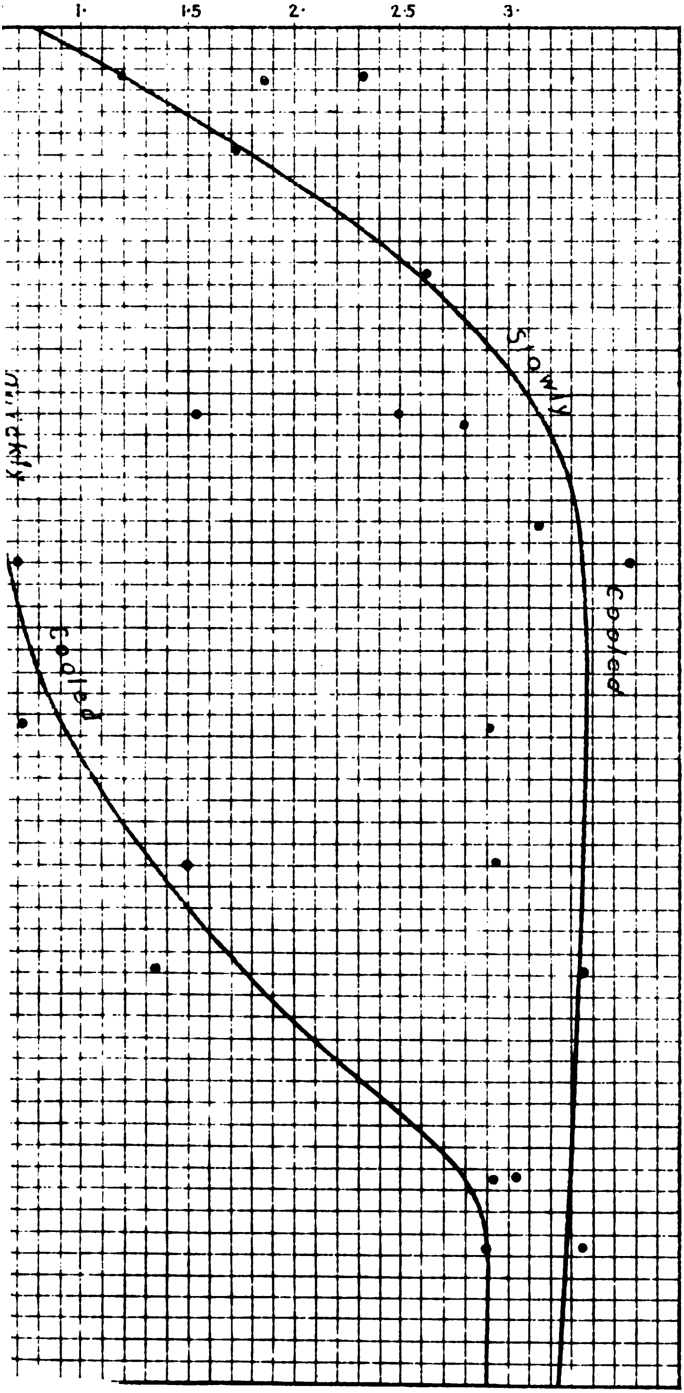
Dr. **Stansfield** said the point he wished to bring forward was this, that, generally speaking, graphite should separate from pure carburised iron when slowly cooled, and that it was the presence of mechanical pressure in the iron which prevented this separation. The intervention of metals like aluminium and silicon appeared to facilitate the separation of graphite, and it would be interesting to know in what way it did this. The action of aluminium and silicon should be studied in two ways: first, the actual effect they had upon the solubility of the graphite in the iron; and secondly, the ease with which the graphite separated during cooling from iron containing aluminium or silicon. These were two different things, and should be regarded separately. In order to obtain further information on the subject, it would be necessary to study the cooling curves of iron containing varying amounts of both carbon and aluminium. The problem was very complicated, but its solution must be undertaken before the action of aluminium on the carbon of cast iron could be fully understood.

Dr. C. B. **Dudley** said that at his American works they had made no experiments with aluminium except a few preliminary ones in the crucible. They did not succeed very well in their experiments in trying to produce aluminium in the foundry. They were all interested in the constitution of iron and steel, and he asked more for information than for any light he could throw on the subject himself, whether it was possible that they were still in the dark in regard to the possibility of oxygen being in both pig iron and steel? He could only throw out a suggestion, but in their experiments with aluminium they had such peculiar test-pieces coming out of the crucible that the thought came to him that there was oxygen, and a reaction between the aluminium and the oxygen. He did not follow it owing to lack of time.

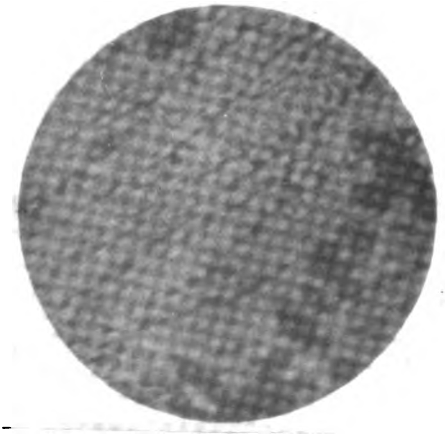
Mr. G. J. **Snelus**, Vice-President, thought it was important to bear in mind the existence of occluded oxygen in steel in any experiments with an alloy. Many years ago at Dowlais he made the earliest experiments ever attempted to estimate the amount of occluded oxygen in the steel. He estimated the amount of active oxygen by the effect it produced upon manganese introduced into the steel, and since then those results had been verified several times. He thought it was a point of very great consequence that the younger experimenters should pay more attention to this question of oxygen in steel. It was a very difficult point to study, but he was convinced that it was a point of very great importance, and it affected any experiments like those where they were examining what was the action of aluminium in throwing out the carbon in the form of graphite. He should like very much to see greater attention paid to the question of occluded oxygen and other gases in steel. It was a point which had been latterly lost sight of. Mr. Windsor Richards did a good deal in the examination of occluded hydrogen and carbon oxide. But the oxygen that was occluded in steel was of very serious consequence in many directions, especially in producing unsound steel in the form of blowholes. Dr. Dudley had raised the question, and it occurred to him that it was so intimately connected with the paper under discussion that, when called upon by the President, he thought it worth while to allude to it.

Mr. R. A. **Hadfield**, Member of Council, said they were very much indebted to the authors of the interesting paper, but he should like to ask why they had selected as a base cast iron containing as much as 0·38 per cent. of graphite? There should be no difficulty in getting a pure carbide of iron, that is, in which graphite is practically absent. He had himself some of this material, and if the authors desired to continue their experiments, such material as they might require was with pleasure at their disposal. Referring to the amount of compression produced by varying loads, he noticed these only gave the total amount of reduction in length by compressions of 77 tons. He should like to know how much permanent deformation was produced by lowering loads 10, 20, and 50 tons. Another important addition to this paper would be to state the melting-point of the different mixtures by the pyrometers. There were

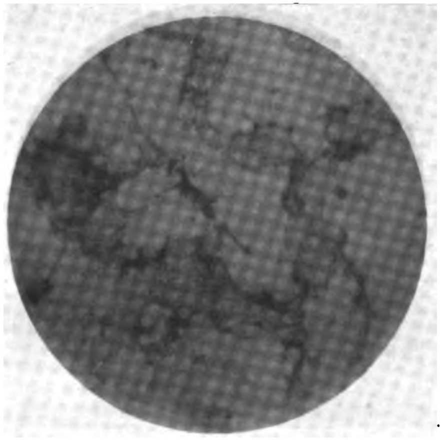
PLATE XIV.



Ballantyne, Hanson & Cº Edinburgh & London.



Pig iron containing 11·8 per cent. of aluminium.



Metal slowly cooled, magnified about 300 diameters.

so many considerations to be borne in mind in a research of this kind that it was important to have all the details possible. This paper had led him to refer to some old experiments of his own when making experiments in manganese steel, when he was desirous to ascertain whether the carbon there present could be in any way made to assume the graphitic form. He tried to effect this by additions of aluminium and silicon, but unsuccessfully. In manganese steel, where the carbon was comparatively low, it was not therefore possible to effect separation. He then thought this might be accomplished in spiegeleisen, where the carbon was much higher, and he took a spiegel containing 12 per cent. of manganese and about 4·8 to 5 per cent. of carbon. To this he added 6 per cent. of aluminium, and then about three-fourths of the carbon was changed into the graphitic form. Although, therefore, it is very difficult in an ordinary way to separate the carbon combined so strongly in spiegel, this showed that it could be accomplished. Not only was it possible to do this, but from an ingot which he made about 2½ to 3 inches square he produced without any difficulty a test bar about 6 inches in length with threaded ends. In other words, without materially affecting the manganese present there was almost a complete transformation of the combined into graphitic carbon, and the material changed its physical properties considerably; instead of being hard enough to scratch glass, it could then be readily tooled. The manganese present was reduced slightly, but with care even the small loss met with could no doubt be avoided. The tensile strength of the material after the change was about 8 tons, and under a compression stress of 10 tons per square inch there occurred a reduction in length of about one-tenth of an inch, and at 40 tons it had shortened 10 per cent. There was no difficulty in repeating the experiment, and it might be interesting to add that, notwithstanding the extraordinary change in the carbon condition, the alloy remained practically non-magnetic. It was suggested to him that such an alloy would be useful for small castings for dynamo bed-plates. There was a considerable future for non-magnetic metal for certain classes of work, and a material such as now mentioned, although of comparatively low tenacity, was as strong as cast iron.

Mr. **Melland**, in reply, thanked the members for the numerous hints as to the continuation of this research. If he had taken up all the points which they suggested to him, the work, such as it was, would have occupied four or five years at least. With regard to the cooling curves, that was an important part of the work, but he did not think of it till half the analyses were made; and as the analysis took up a great deal of time, he thought it would perhaps be better to deal separately with it. With regard to what Dr. Dudley said about the loss of aluminium, he could not account for that by the presence of any amount of oxygen in the cast iron. In the case of steel where they had practically no carbon present, they could easily conceive a good deal of oxygen there as oxide of metal or carbon monoxide, but in this cast iron he did not think they could have it. Still they had a very large percentage of loss of aluminium where the amount added was small. He was very pleased with what Mr. Hadfield had said about the separation of the graphite from the ferro-manganese or spiegeleisen. That suggested a use for aluminium. It was generally said that it might be interesting from a theoretical point of view; but that the metal was so expensive that it could not possibly be used. A small amount, however, would effect a very great softening of the metal, and it might be of practical value at once.

The **President** said Mr. Melland was one of his own pupils, and the joint authors deserved a hearty vote of thanks.

The following paper was then read :—

SUGGESTIONS FOR THE IMPROVEMENT OF ROLLING-MILLS.

By LOUIS KATONA, Resicza, Hungary.

The modern construction of the rolling-mill represents the results of continued evolution upon a very primitive original, and the course of development of the widely differing types now in use will be well known to the members, for it may be said that it has entirely taken place during the present generation, and so many of those who have designed or built the plant have submitted their efforts to the consideration of this Institution. Speaking generally, in the rolling-mill four distinct factors are to be considered. These are: the engine or driving motor, the fly-wheel which compensates for the irregular action of the engine, the power transmission gear, and the rolls themselves. Great improvements have been made in all these parts, but certainly more attention has been paid to perfecting the steam-engine. Nevertheless the steam-engine is not in itself altogether suitable for the purpose, inasmuch as fly-wheels have to be used, or two or three cylinders have to be coupled on to one crankshaft in order to overcome the effects of the varying pressure of steam when high expansion ratios are in use, as in modern practice. In comparison it may indeed be said that the alterations in the gearing and in the rolls have been but slight. In the rolling-mill the cross section is diminished step by step, and at the same time the length of the material under treatment is increased by submitting the work to the consecutive operation of a number of passes. These passes are formed in three or four sets of rolls, and in two or three high mills, so that the multiplication of the mills necessitates much reduplication of the gears. Amongst the defects due to this may be mentioned the slackness in the couplings, the play between the pinions, the unprotected situation of the bearings, and the difficulty of adjusting the grooves, besides which there are many other points that will readily occur to any one in charge of a rolling-mill.

At the present time there are at least three types of mill in general use, viz., pull-over or two-high, non-reversing mills with fly-wheels, three-high mills with fly-wheels, and two-high reversing mills. Each of these is used for rolling all sorts of shapes and sizes, but in all of them the above-mentioned defects occur, and it is intended in this paper to suggest some means for counteracting them.

In rolling iron and steel as considered below, all the preceding and subsequent metallurgical processes will be neglected, and attention will be mainly confined to two points—the consumption of power and the waste of fuel and material. Much ingenuity has been expended in all industries in efforts to obtain economy in these directions, but it must always be remembered that over-refinement may have an effect the reverse of that which is intended. The size and weight of the raw material for the production of a given section of iron or steel is limited unconditionally as regards rolling-mills now in use, and there does not appear to be much prospect of great improvement in this direction for the present, although altered conditions often produce unexpected results. A very different state of things is seen, however, when consideration is given to the possibility of altering the ratio between the total amount of power used in driving and the proportion which is absolutely used in reducing the cross section of the work. In other words, it may be possible to greatly increase the efficiency of the rolling-mill.

The great defect of the present system of rolling-mill plant lies in the enormous masses that have to be set in motion to no effect. At any moment, the only part of the mill which does useful work is the particular groove through which the metal is passing. All the power consumed in driving the rest of the mill is so much wasted energy. This includes all the power expended in the idle rolls, the couplings, the gearing, and in the fly-wheel used in two and three high rolls.

Indicator diagrams were taken from the cylinder of an engine driving a two-high mill provided with a fly-wheel and rolling girders 220 millimetres deep. Running unloaded at 60 revolutions per minute, the horse-power developed was 81·3, which served to keep the engine, rolls, gearing, and fly-wheel in steady motion. Calculated from the frictional pressures, &c., the amount was

87·2 horse-power. When fully loaded, eight diagrams from the same cylinder showed 284·3, 269·2, 288·5, 296·0, 342·5, 366·5, 352·0, and 401·0 horse-power, or an average of 325·0 horse-power. The requirements of power, speed, and all other conditions remaining constant, this shows that no less than 25 per cent. of the average power is consumed in driving the great masses of the mill.

A second train used for rolling merchant iron was tested when producing hoop iron. It consisted of four three-high sets of rolls in one line, and twelve three-high sets in another line. When running idle the power absorbed was 68·8 horse-power. When the hoop iron was passing through the grooves, 28 indicator diagrams gave the following figures:—238·0, 231·8, 246·5, 236·0, 236·5, 93·7, 101·8, 127·0, 82·2, 108·0, 113·6, 112·0, 129·6, 235·0, 272·0, 259·0, 254·0, 247·0, 254·0, 193·0, 179·2, 260·0, 164·8, 195·0, 218·0, 208·5, 128·0, 132·8, an average of 187·7 horse-power. Here also all the conditions were uniform excepting the work done, and so it is evident that 36·6 per cent. of the average development of power was taken for revolving large dead weights.

Beyond this, however, there is another factor to be taken into consideration. The engine is only called upon to exert its maximum power during part of a loaded run, partly in consequence of the unequally distributed pressure in the successive passes and partly on account of the difference in temperature between the ingot and the finished work. The greatest power is called for when the material is in the last finishing passes, whether it consists of girders, rails, angles or other shapes, hoop iron or wire rod. Thus from a minimum of 25 per cent., the loss increases with the number of the sets of rolls and with the ratio of the weight of the rolled material to the weight of the machinery, so that it may reach 36·6 per cent. or even 40 to 50 per cent. in some cases. It may even happen that the useful work is occasionally only a small percentage of the total. As far as the author is aware, numerical data of this character has not been published hitherto, but the great care taken in lubrication of the rolls show that every one is well aware that serious losses of power do exist.

The second great defect in the arrangement of rolling-mills is that more or less of the total number of revolutions are wasted as far as useful work is concerned. During the operation of rolling rails on a three-high mill, for instance, some time is lost in raising the ingot after it has passed the first groove so that it may enter the second pass, and further time is taken in shifting it laterally to the third pass, and so on. All this time the rolls and the fly-wheel are being driven with the expenditure of steam. It is true that the steam consumption is less, but a little calculation shows somewhat surprising results as regards the waste of power during these idle intervals. In order to appreciate the losses in their right measure the different types of mills must be considered separately.

Two-high mills with fly-wheels are used at several works for rolling angle, tee, and other sections of small and medium sizes. New mills of this type are not built at the present time, but the existing plants are not being replaced. The number of loaded revolutions of such a mill is very small, and the same statement is true of the non-reversing plate-mill. In one case the total number of revolutions of the engine, when I-beams 280 millimetres deep were being made, was 6010, but of this number only 540 revolutions, or 9 per cent., did useful work as calculated by the total length of the material rolled. On another occasion the total number of revolutions was 5537 when making plate billets, and the useful number 404 or 7·3 per cent. On non-reversing mills producing plates 3 to 6 millimetres in thickness and 1 by 2 or 3 metres in area, the total number was 827 revolutions, of which only 47 or 5·7 per cent. did the necessary work.

Three-high mills with fly-wheels are in general use for producing the most different profiles of iron and steel. In smaller sizes as high speed trains they make common merchant iron, hoop iron, and wire rod; in larger sizes they produce beams, rails, and other large sections; as plate-mills their work is to manufacture sheets, boiler and ship plates, &c. The loaded run changes according to the shape and size of the rolled pieces and their longitudinal dimensions, and according to the nature of the appliances and machinery at hand. The method of making the observations being the same as before, three-high trains show 37 per cent. as their proportion of loaded run to the total runs under favourable conditions when producing girders of symmetrical section which do not require any turning. With skilled and careful workmen, doing all the work by hand, the average, as a rule, remains under 30 per cent. When producing channel iron which has to be turned after each pass, the loaded runs decrease to 21 per cent.

On three-high mills of medium size producing lighter sections or merchant iron, the number increases from 50 per cent. up to 75 or 80 per cent., depending on the skill of the workpeople and the length of the rolled pieces. On the lightest trains rolling hoop iron or wire rod it may attain to 90 or 95 per cent. But as the ratio of loaded runs increases favourably to the total runs on these trains, the first mentioned defect, *i.e.*, the largeness of dead weight revolved, steadily increases in proportion. These light trains consist, as a rule, of 8 to 16 sets of rolls, each set having three rolls and a corresponding number of couplings. The weight is sometimes augmented by spur wheels or belt gearing interpolated for the sake of raising the circumferential speed of rolls. When the work is in the last set of rolls the pressure is increased not only in the bearings of those rolls, but also to some degree in the bearings of every roll, in consequence of arrangement of loose couplings, and hence the loss of power increases in proportion as the ratio of unloaded runs is improved.

On three-high mills it is customary to manufacture plates from 20 millimetres down to 0·4 millimetres in thickness. The length and width of these plates do not differ greatly, boiler, ship, &c., plates or sheet iron, black and tinned, for example. According to their dimensions and their quality the handling may require more time than usual after each pass. It will be necessary to enter them into the rolls alternately in the direction of their length and width, to examine their surfaces carefully after each passage, and to measure the length and width as well as thickness more frequently. The percentage of loaded runs will decrease as an effect of these precautions. Under favourable conditions the ratio can go up to 15 or 20 per cent.; in sheet iron trains, as a rule, it remains at 7 to 20 per cent.

In those types of trains with two and three high rolls combined, the double two-high trains are in the middle between the simple two and three high trains. The ratios vary with the section and other dimensions of the pieces rolled and with other factors mentioned above. In certain cases they may be as high as 55 per cent. in the combined trains of two and three high sets or 60 to 70 per cent. in double two-high trains. However, as the ratio of loaded runs improves, the amount of dead weight driven also increases, as is characteristic of the light merchant trains.

Reversing-mills work, as a rule, without fly-wheels, though a fly-wheel has been used, as Mr. Ledebur states, but it did not come into general use. This type of mill may be used to produce any of the larger sections, such as rails, I-beams, constructional plates of great length, boiler and ship plates, &c., but their special use is for cogging ingots. The ratio of the loaded runs is closely dependent on the section, and on the efforts directed to economising the steam consumption. With short pieces the ratio will be reduced in consequence of the numerous revolutions made before and after the piece has entered and passed the rolls. With larger slabs the same result will be obtained for a similar reason. As the engine works near to the limit of its maximum power, the man in charge has to start early to obtain sufficient momentum to carry the work through. The number of unloaded revolutions, therefore, is increased at the start, and they are made with great steam consumption. A little slackness on the part of the men in stopping these large engines at the proper moment is also provocative of waste.

The ratio of loaded runs producing boiler plates is 37 per cent.; constructional plates in longer lengths, 30 per cent.; plate billets of lighter size and section, 25 to 30 per cent.; girders of medium size up to 240 millimetres height, 50 per cent.; axles for railway rolling stock up to 150 millimetres in diameter and 1300 kilogrammes in weight, 28 per cent.

These data have been gathered under the most favourable conditions for the trains to-day in use, in each case as regards steady work, careful and skilful workpeople, and experienced foremen, so that the calculations and statements given below may be regarded as well within the bounds of probability.

Given the consumption of fuel for producing steam for engines of different trains, the amount of wasted fuel can now approximately be calculated. The consumption of coal under the boilers per ton of finished material may be given as follows:—Girders or other section iron on two-high trains, 800 kilogrammes (1760 lbs.); rails on three-high mills, 440 to 450 kilogrammes (968 to 990 lbs.); I-beams on the same train, 640 to 680 kilogrammes (1400 to 1500 lbs.); constructional plates of greater length or I-beams and axles on reversing trains respectively, 850 to 900 or 600 to 700 kilogrammes (1870 to 1980, or 1320 to 1540 lbs.); on commercial and high speed trains 1000 to 2000 kilogrammes (2200 to 4400 lbs.). Of course the quantity used will vary with the quality of the coal, but the value of the coal and the pecuniary equivalent of the waste will both depend on its caloric value.

Rolls and Products.	Coal Consumption per Ton.	Unloaded Runs.		Loaded Runs.		Loaded Runs.		Coal Wasted.	
		Number.	Power Used.	Number.	Power Wasted.	Number.	Power Used.		
	Kilos.	Per C.	Per C.	Per C.	Per C.	Per C.	Per C.	Kilos.	Per C.
Two-high train—I-beam	800	91	30	9	30	9	70	660	82
Three-high train—Channel iron . .	680	79	40	21	40	21	60	515	76
Three-high train—I-beam	650	66	40	34	40	34	60	430	66
Three-high train—Commercial iron .	1200	20	70	80	70	80	30	890	74
Reversing two-high—I-beam	650	50	30	50	30	50	70	300	46
Reversing two-high—Axles	650	72	30	28	30	28	70	390	60
Reversing two-high—Boiler plates . .	850	63	30	37	30	37	70	455	54
Reversing two-high—Construct. plates .	850	70	30	30	30	30	70	500	59

The calculation for the two last columns was made as follows:—The percentage number of runs, both unloaded and loaded, are multiplied by the power used in driving the unloaded mill, and the number of loaded runs is multiplied by the additional power used in driving when loaded. These products are then added together. For instance, in the first case—

$$30 \times 91 + 9 \times 30 + 9 \times 70 = 2730 + 270 + 630 = 3630.$$

Of these products, the first two, 2730 + 270, or 3000 out of the 3630, represent the waste, and from this the proportion of the 800 kilogrammes in the first column may readily be calculated as 660 burnt to waste. The steam-producing capacity of coal is taken as uniform in spite of the variable amount of steam consumption in the unit of time. The length of steam-pipes, the large evaporating surfaces required in the boilers, the throttling of steam during the unloaded runs, &c., are amongst the defects that may be mentioned, but are to some extent counterbalanced by other circumstances. Under the most favourable conditions, therefore, the last two columns represent the minimum of waste, and the average will exceed it in most cases.

The number of times that the material has to be treated in separate mills must also be taken into consideration. In new iron and steel works intended for the production of large outputs of very varied sections, Bessemer or open-hearth steel is cast into ingots weighing from 2 to 3 tons; the ingots after cogging are cut into billets for rails or beams of two or three lengths, or for boiler plates and structural iron of standard sizes, and the rolling and finishing of the rails, beams, plates are carried out on second trains. In the manufacture of small sections or merchant iron, the billets require to be drawn down to smaller dimensions and lighter weights for their further manipulation, and this is done on a second train, and then the iron or steel is rolled to the intended section in a third mill. In some cases, as with hoop iron or wire rod, a fourth mill may be required to finish the operation.

The distribution of grooves into detached trains and the number of passes required for producing certain sections may vary widely. The greater the difference between the sectional dimensions of the ingot or billet and of the finished material, the more grooves has the material to pass through; and accordingly, in consequence of the defects of the steam-engine and rolling-mills, the larger is the waste of motive-power consumed by unloaded runs and revolving dead weights. Hence it will readily be granted that the quantity of fuel contained in the last two columns of the table above may be increased from 50 to 200 per cent. according to the size and shape of the output.

Beside these defects which have been so fully dealt with, there are many smaller matters which enhance the price of the rolled material and their co-operation is a factor by no means to be neglected. The simultaneous motion of many rolls has to take place in spite of the imperfect power-transmitting and coupling arrangements and the unsuitable construction of bearings. Every shock and impact in the loose couplings causes great waste of power; they impair the steam-engine and hasten the destruction of many parts. The defective bearings for the necks of rolls result in much waste of lubricant, and the wear and tear of the necks and bearings due to their unprotected situation is excessive.

The form of the grooves turned in the rolls is determined on principles found to be correct by experience. The sequence of the forms from the first to the last groove and the dependence of each groove on the preceding one is a function of the plasticity of the heated metal. The limits of ductility must not be surpassed, or longitudinal or transverse cracks will be formed in the iron passing the rolls, and the work must gradually be broken down into the shape required. To use the words of rolling-mill managers, the rolled piece should fill the groove exactly, and no fins should be formed. There is a lack of precise laws; experience is the only guide at the present time. Even if those laws were known, the efficiency of the application of the motive power would still be a variable factor for each groove. The rolling surfaces of separate grooves are called into requisition in different degrees in consequence of the increasing longitudinal dimensions of the rolled piece, so that they suffer more and more by wear and tear, and are sooner unfit for use. The worn-out grooves have to be re-turned, and this necessitates turning the whole surface of the roll, even on the parts where very little or no repair may perhaps be required.

A disadvantage of the rolling-mills at present used, and one that cannot be neglected, is the difficulty accompanying the accurate set of the grooves. This includes not only the congruence of the last or finishing groove with the intended section, but also the corresponding succession of grooves arranged in the same rolls, or in the rolls of another stand. Every one connected with the management of rolling-mills knows well that the setting of rolls with accuracy very often necessitates much expenditure of labour, material, and time.

The conclusions deduced from these observations have led the author to seek for a solution of the problem under the given conditions, *i.e.* to construct a train in which the disadvantages enumerated above would be eliminated as completely as possible, and the problem does not appear to be difficult.

To avoid revolving dead weights, each groove is arranged in a separate pair of rolls. The dimensions of the rolls are settled by proportioning the material according to the power required. The elimination of unloaded revolutions is closely connected with the decrease of the weight, because fewer strokes of the engine are necessary to get up speed, and the smaller masses come to rest more speedily after the work is done. With the same object in view, it is desirable to use those forms of motors and driving-gears which require the shortest time possible for developing the maximum power. Under ordinary conditions the electromotor is preferable; but there are cases, however, where hydraulic engines or belt transmission may be advisable.

These ideas may be carried into practice in the manner represented in Plates XVI. and XVII., in which Fig. 1 is an end view and Fig. 2 a side view of a stand of rolls, each pair of rolls having a single pass only, while Fig. 3 is a suggested plan for a mill plant designed to roll girders 120 millimetres (4¾ inches) in depth, from roughed slabs 150 by 180 millimetres (6 by 7 inches) in section, and weighing 370 kilogrammes (815 lbs.).

Each pair of rolls has a single pass only, and the rolls approximate to discs in form. They are made of steel to further reduce their weight, and their dimensions are proportioned to the work they have to do. The rolls are made with solid webs, or each roll may have a hollow or double web instead. In certain cases, as, for instance, in the preliminary reductions in a cogging mill, the rolls may be replaced by segments of a circle, to which a reciprocating motion will be given. The discs or segments are keyed on steel shafts *i*, running in bearings *a*, *b*, mounted on the bearers *c*, *d*. The bearings on the left-hand side are closed by end caps, while the shafts pass through the right-hand bearings to receive worm, belt, or other driving-gear. The bearers *c*, *d*, at the top and the bottom respectively, are rigidly connected to form top and bottom frames, which are adjustably held at the proper distance apart by the sixteen nuts *f*, on the four screws *e*. By manipulating the nuts *f*, the height and vertical dimensions of the pass may be regulated. Double wedges *g*, or right and left hand screws, are inserted to assist in holding the bearings of the top and bottom rolls at the requisite distance apart. The bottom frame has four legs on which it stands. The rolls will be coupled direct to the engine or motor, which is fixed on the bed-plate. The plan of the mill for light sections is shown in Fig. 3, and in section in Fig. 4. The rolls are placed side by side, with travelling or swinging roller tables to transfer the work.

In this plant the author believes it will not be necessary to change the roughing rolls on account of the varying sections required in the finished material, and that they will only have to be replaced on account of the wear in the bearings or in the grooves. Accordingly the details of the housings may vary somewhat from that shown. It is only in mills used for rolling medium sizes of merchant iron, for which the demand is very variable, that constant changes will be necessary. The other arrangements required at the present time for quick rolling will not vary greatly, and the auxiliary engines and other machinery will be retained in their present form.

It will be clearly seen from these statements that rolling-mills erected on the plan here proposed ought to have many and great advantages over the present system, and that the improvements do not exclusively relate to the economy in the fuel used for producing motive-power. Of the amount of that saving the table given above affords some indication, but definite knowledge can only be gathered from practical experience, and as yet a mill of this type has not been built.

The following advantages may be enumerated:—The necks of rolls and the bearings will last longer, owing to the reduction of the ratio of unloaded runs and to the diminution of the pressure on the bearings. Their design may be improved to obviate the penetration of dust and dirt, the detrimental effect of which is so obvious, and they will not be exposed to the shocks and impacts caused by the loose couplings. A saving in lubricating material may also be effected, as a better type of lubricator may be fitted in place of the present rough-and-ready methods of oiling and water-cooling. The omission of loose couplings, and the consequent reduction in breakages, need only be mentioned to be appreciated. Labour will be reduced, and will be directed into its proper channel as a controlling factor instead of being used in the form of brute force. The mill train will be capable of a very large output on economical lines, but at the same time it will feel to a much smaller extent any fluctuation in the demand from the iron markets.

The amount of work done on the ingots during the rolling and the coal consumed under the boilers will vary in proportion to the quantity of rolled iron delivered. For example, the twelve pairs of rolls required for producing girders of medium size can all work simultaneously in case of need when the market wants large quantities; but if the consumption falls off, the number of pairs of rolls working simultaneously will be reduced to suit the circumstances, and the coal consumption will be correspondingly lowered. On hoop iron or wire rod mills, automatic starting and stopping gear for the engine, operated by the work as it enters and leaves the rolls, would almost eliminate the need for workpeople, who would then only be required to control the continuous co-operation between the heating furnaces and the mills.

The waste of material, time, and labour which the accurate setting of grooves entails will be nearly totally eliminated, and the changing and setting of a number of small rolls will be very much easier as compared with the huge masses that now have to be moved, while the saving in storage and in repairs will be very great. Duplicate sets of rolls and sets suitable for a very large number of sections could be kept, without waste of interest on idle capital. In conclusion, the author is strongly convinced that the results to be obtained in practice will far transcend those foreshadowed above, and that the installation of his system for rolling iron will effect great changes in the technology of iron as well as in its relation to common life.

DISCUSSION.

Mr. E. P. **Martin**, Past-President, said this was a very important paper, containing a large amount of information, and he suggested that, as time was limited, written communications should be forwarded to the Secretary.

Mr. S. S. **Horsfield** (Blaenavon, Monmouthshire) had read Mr. Louis Katona's paper with much interest, but he could not agree with some of his statements, and he also failed to see all the advantages claimed by the author for his design of mill. To deal with this paper in detail would be a lengthy matter. He would himself make only a few observations.

Mr. Horsfield subsequently forwarded the following contribution to the discussion:—

All practical men will admit that in a "two-high pull-over mill" there is a great waste of motive power, but in the case of a "three-high mill" it is, or should be, quite different, unless the engine is not powerful enough for the work. A "three-high mill," consisting of roughing and finishing rolls, could almost always be kept loaded (perhaps not up to its full capacity), as two pieces can be dealt with at the same time—one piece at the finishing and one at the roughing rolls—and one piece travelling from the cogging to take their place. If there is only one bloom at a time in the mill, then that mill is not doing the work it should be doing, and consequently there will be a great waste of steam.

Then, as regards another type of mill—the two-high mill driven by a pair of reversing engines, the author states that the man in charge of the engine must start early to obtain sufficient momentum to carry the work through. This must be a mistake, as the engine receives very little steam until the rolls grip the piece, and then only does the engine receive full steam.

My object in making any comment on this paper is not so much on the question of waste of steam and coal consumption, as on the design of mill by Mr. Katona. The question of waste of steam and coal consumption depends in a great measure on the conditions one is working under, including management.

The author states that, by having only one groove in each pair of rolls instead of the required number of grooves in one pair of rolls, that it will economise material, time, and labour. In my opinion, it would be the reverse. Consider for a moment. To produce an ordinary sectional piece of steel (angles or rails), one requires at least four or five forming grooves, which means four or five pairs of rolls in the proposed mill. Suppose, when rolling angles, tees, or other similar sections, how can any one roll ⅜-inch and ½-inch thick in the same rolls if there is only one groove? It means changing rolls. Suppose it were possible to avoid changing rolls, could the author give any idea as to the time it would take to adjust the rolls, as there are eight nuts to loosen on each groove or pair of rolls, which means 32 to 40 nuts to be dealt with?. This must take a considerable time, considering that the screws must be at least 4 or 5 inches in diameter to resist the strain which they will be subjected to. Whereas by having the five grooves in one pair of rolls, only six parts have to be dealt with in adjusting the rolls, and which can be done in two to three minutes, or even less.

Can the author give any idea as to the time it would take to change and fix up even five pair of rolls, and the number of men required to work the mill? because it appears to me that the greater the number of grooves worked the greater the number of men required.

The author also suggests that the tables conveying the piece from one groove to another shall be swinging ones. Will they not also have to be feeding ones, or what is to carry the piece into the rolls if the piece is at all heavy?

The author also suggests using steel rolls for lightness. My experience is that steel answers very well for cogging and roughing rolls, but is objectionable for finishing rolls, as the heat causes the steel to crack (surface cracks), after working a short time.

It is also suggested that the cogging rolls shall be discs or segments keyed on steel shafts. I am afraid it would not be a very substantial job. It answers very well for a short time as a patch. I have tried it with finishing rolls.

In my opinion it would be found a difficult matter to roll a number of sections of steel in proposed mill. It might do very well for girders, but a mill cannot be expected to be running

PLATE XVI.

FIG. 1.

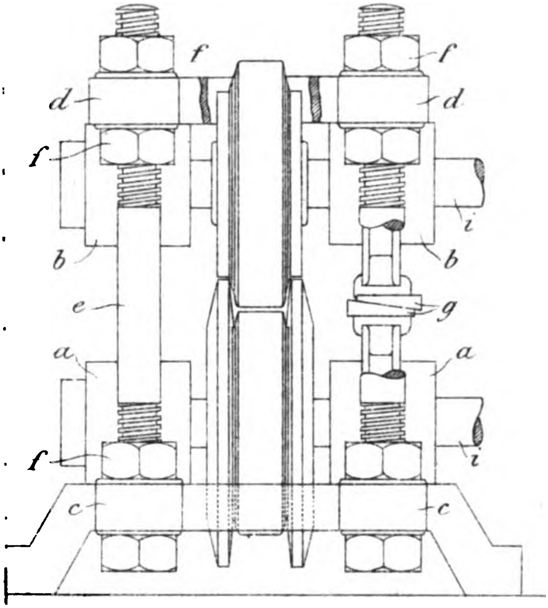
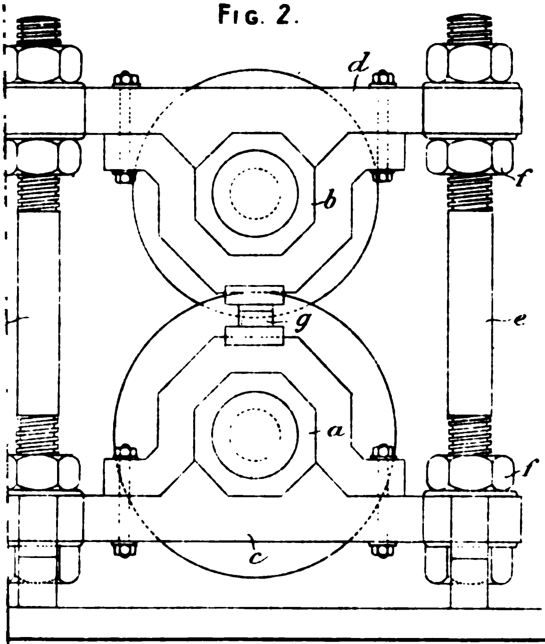


FIG. 2.



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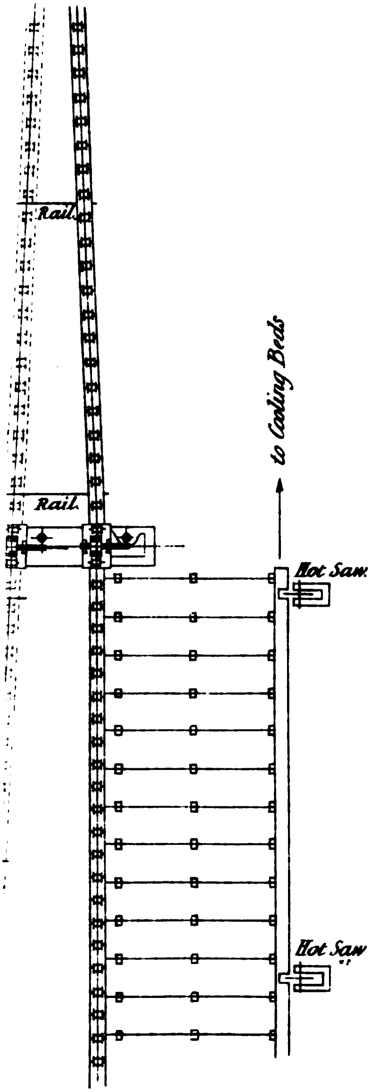
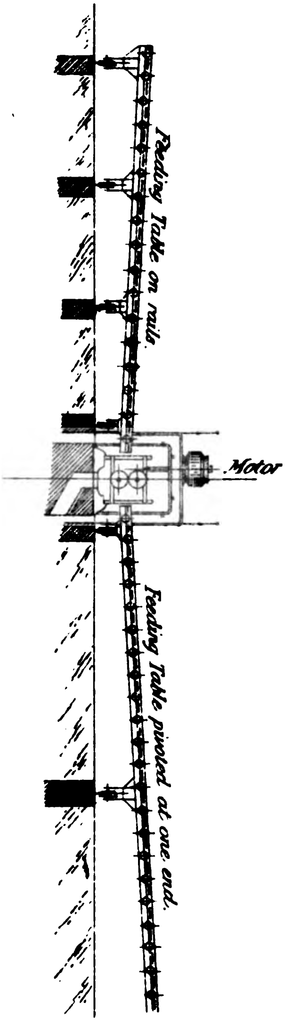


FIG. 4.



Ballantyne, Hanson & Co. Edinburgh & London.

constantly on girders. How would the author roll "round bars" or "axles" by hand in this mill?

It would be a difficult matter for any one to prove what is the best type of rolling-mill, because it depends on what class of work you are engaged in. For instance, the author states that in rolling channels in a "three-high mill" a great deal of time is lost by having to turn the bar over every groove. My experience is that a "three-high mill" is not suitable for rolling channels; a "two-high reversing mill" is far more preferable. On the other hand, a "three-high mill" is far more economical for tin bar and other plain work than a "two-high reversing mill." A great deal more might be said of other types of mills mentioned in the paper, including Mr. Katona's own design. In my opinion this new design of mill might, as I have already stated, be used for rolling girders (I don't approve of the housings), but I think would never do for rolling ordinary merchant and sectional steel, other than girders or similar section.

How is the reciprocating motion given to the segments of rolls in a cogging-mill?

The President proposed a cordial vote of thanks to Mr. Katona for his paper.

The President, referring to the remaining papers on the list, said that Professor Bakhuis-Roozeboom was one of the greatest authorities on the question of solutions generally, and it was shown in his excellent paper how completely the carburised iron fell into line with ordinary salt solutions, and also the extreme importance of allotropy in connection with iron.

The paper by Baron H. von Jüptner was on the constitution of slags and the part they played in iron. They must also take that paper as read in spite of its great originality. Many years ago he endeavoured to classify slags, and here in this paper was really available a most interesting classification.

Dr. Stansfield had a continuation of a paper that he had already favoured them with, and this was in every way worthy of the first part, and there was no higher commendation. With their best thanks to the authors for these valuable papers, they must conclude the business part of their meeting.

VOTES OF THANKS.

The **PRESIDENT**: This meeting has been in every way a most charming one so far as it has gone, and I now propose "That the best thanks of the Iron and Steel Institute be hereby tendered to the chairman, Mr. Robert de Wendel, and to the members of the Local Reception Committee, for the great cordiality of the welcome extended to us, and for the arrangements, ably planned and successfully carried out, for the convenience, instruction, and pleasure of the members during the present meeting." That is the first part of a comprehensive motion. The second is: "That the best thanks of the members be also given to the President and Council of the Société d'Encouragement pour l'Industrie Nationale for their kindness in granting the use of their building for the purpose of the meeting." I need not dilate on the Société to any great extent, except that I would mention that this is the nearest analogue to our Society of Arts. It is over one hundred years old, and Dumas took the greatest interest and worked very hard for it, and is still an active member, and Mr. Carnot is now president. We have for a third time been received in this hall, and our warmest thanks are due to the Société d'Encouragement pour l'Industrie Nationale. The third part of the motion is: "That the best thanks of the members be given to the President, Council, and the Members of the Comité des Forges for their hospitable reception." When we remember how magnificently we were entertained last night, and the kindness of the Comité in providing music and an intellectual treat for us, we must feel that our gratitude will be not only very deep but very lasting. There are other thanks which I can hardly yet anticipate, except on the ground that gratitude is a lively sense of favours to come. We were received by Mr. Schneider at the Le Creusot Pavilion, and we are very grateful to Mr. Chapman, who has placed his office at our disposal, and also for the most excellent services of Mr. Vaslin. I hope that we shall have an opportunity in London of expressing the warmth of our feelings to Mr. Vaslin for his invaluable help. It is difficult here to do any one thing, but he has done very many things, and his efforts have been crowned with the most successful results. As to the rest of our programme, we shall be very grateful to Colonel Jekyll and Mrs. Jekyll for receiving us this afternoon. Then there will be a reception of some of us by the Minister of Public Works. We will thank them separately after the events when we return to London. I now move that the comprehensive resolution that I have read to you be adopted.

The vote of thanks was seconded by Mr. W. **Whitwell**, President-elect.

Mr. A. **Greiner**, Member of Council, proposed a vote of thanks to the President in graceful terms.

Mr. T. **Nordenfelt** seconded the vote, which was carried with acclamation.

The **President**, in reply, said: I must say a few words, but the only words are words of gratitude. In coming here—and I am glad you have come here in such numbers—I have only one thought, How we who live across the Channel can show our love and appreciation for France—this paradise of France, which we visit so frequently. We all feel, coming to her shores, that we enjoy nothing but "liberty, equality, and fraternity."

The following papers were taken as read:—

THE CONSTITUTION OF SLAGS, AND THE PART THEY PLAY IN THE METALLURGY OF IRON.

BY THE BARON JÜPTNER VON JONSTORFF (DONAWITZ, AUSTRIA).

THE various inter-reactions which take place between slag and metal represent one of the most important factors in most metallurgical processes. It may, therefore, not be out of place to consider from the modern point of view iron slags and some points of connection with the varying reactions which take place between them and iron.

Ledebur was the first to look upon slags as solutions, and not as complicated chemical compounds. He says on this point:* "All constituents of slags, and especially the before-mentioned oxides (metallic oxides and those of silicon, phosphorus, &c.), of which slags principally consist, occur together in quantities which vary extremely the one to the other, and are quite without relation to the laws of combination. Hence it follows that a slag need not consist of a single chemical compound, such, for instance, as a silicate of definite formula, but is to be viewed as a solidified solution in one another of different chemical compounds. It has been already pointed out that these compounds consist chiefly of the oxygen compounds of the metals and non-metals." Further,† he observes that "borax and microcosic salt serve in their molten condition as excellent solvents for all sorts of oxides, and they solidify with these to 'glasses' of homogeneous composition, no matter how great their relative weights are. If silica or phosphoric acid combine at high temperatures with lime, magnesia, ferrous oxide, or other substances, there is no reason to assume that we have not to deal in this case with a simple solution of the various substances in each other, but that absolutely definite chemical compounds have to be formed."

"That definite chemical compounds may form in a solution, and consequently also in a fluid slag, is, however, not to be doubted. Usually these compounds only become recognisable, it is true, when the slag solidifies or subsequently." The following shows how accurate are these views of Ledebur's. To get a better general idea of the constitution of slags, we will divide these into three groups: (1) Silicate slags, which consist of metallic oxides and silica; (2) Phosphate slags, consisting of metallic oxides and phosphoric acid; and (3) Oxide slags, which consist of metallic oxides.

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* *Handbuch der Eisenhüttenkunde*, 2nd ed., vol. i. p. 175.

† *Ibid.*, p. 176.

I.—Silicate Slags.

Before dealing with silicate slags, we will consider the various silicon hydroxides. Of the various possible hydrates of silicic acid, only the ortho- (H_4SiO_4) and meta-silicic acid (H_2SiO_3) are known in a free state. Numerous other pyro- or poly-silicic acids are formed by the separation of water from the two above mentioned, as, for instance, the di-silicic acid ($H_2Si_2O_5$) and the tri-silicic acid ($H_4Si_3O_8$). They are, however, not known in a free state, but the silicates corresponding to many of these occur as minerals. The following table, borrowed chiefly from Weltzien, furnishes a summary of all possible silicic acids :—

Name.	Silicic Acids.			
	Mono.	Di.	Tri.	Poly.
2. Basic or meta	H_2SiO_3	$H_2Si_2O_5$	$H_2Si_3O_7$	$H_2Si_mO_{2m+1}$
4. Basic or ortho	H_4SiO_4	$H_4Si_2O_6$	$H_4Si_3O_8$	$H_4Si_mO_{2m+2}$
6. Basic . .	H_6SiO_5	$H_6Si_2O_7$	$H_6Si_3O_9$	$H_6Si_mO_{2m+3}$
8. ,, . .	H_8SiO_6	$H_8Si_2O_8$ *	$H_8Si_3O_{10}$	$H_8Si_mO_{2m+4}$
10. ,, . .	$H_{10}SiO_7$	$H_{10}Si_2O_9$	$H_{10}Si_3O_{11}$	$H_{10}Si_mO_{2m+5}$
12. ,, . .	$H_{12}SiO_8$	$H_{12}Si_2O_{10}$	$H_{12}Si_3O_{12}$ †	$H_{12}Si_mO_{2m+6}$
2*n*. ,, . .	$H_{2n}SiO_{n+2}$	$H_{2n}Si_2O_{n+4}$	$H_{2n}Si_3O_{n+6}$	$H_{2n}Si_mO_{2m+n}$

The formulæ shown in large type in the table are general formulæ for silicic acid, which, however, have only a real value when both n and m are greater than o. It is self-evident that isomers are also possible in silicic acids, such, for instance, as—

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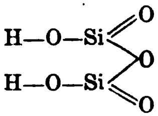
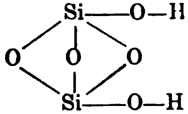
* Impossible, as it is only 2 (H_4SiO_4).

† Impossible, as it is only 3 (H_4SiO_4).



and



and similarly that some of these may only represent an aggregation of molecules of simpler silicic hydrates. This latter case *may* happen if the formula of a poly-silicic acid is the multiple of a simpler form, and it *must* happen if it represents a multiple of an ortho-silicic acid. In this way, too, silicates may be subdivided, and one obtains, for instance, meta monosilicates, ortho-disilicates, 6-basic-trisilicates, &c. In metallurgy another series of formulæ are usually employed, and this is shown in the following table together with the corresponding chemical formulæ:—

				Molecular Formula for	
Oxygen ratio. $\frac{\text{Acid}}{\text{Base}}=$	Older Chemical Description.		Metallurgical Description.	Monoxide Bases.	Sesqui-oxide Bases.
1 : $1\frac{1}{2}$ . .	One-third .	Silicates.	Sub-silicate .	$\overset{\prime\prime}{R}_3SiO_5$	$\overset{\prime\prime\prime}{R}_2SiO_5$
1 : 1 . . .	Semi . .		Mono-silicate	$\overset{\prime\prime}{R}_2SiO_4$	$\overset{\prime\prime\prime}{R}_4Si_3O_{12}$
$1\frac{1}{2}$: 1 . . .	Three-quarter		Sesqui-silicate	$\overset{\prime\prime}{R}_4Si_3O_{10}$	$\overset{\prime\prime\prime}{R}_8Si_9O_{30}$
2 : 1 . . .	Mono . .		Bi-silicate .	$\overset{\prime\prime}{R}SiO_3$	$\overset{\prime\prime\prime}{R}_2Si_3O_9$
3 : 1 . . .	$\frac{3}{2}$ . . .		Tri-silicate .	$\overset{\prime\prime}{R}_2Si_3O_8$	$\overset{\prime\prime\prime}{R}_4Si_9O_{24}$

In order to obtain a more thorough knowledge of the constitution of silicate slags, use can be made of the melting-point curves and of the microscopic composition.

With regard to the latter, it may once for all be stated that amphibole minerals, felspar minerals, free acids, and free oxides have never been found in slags. The former, too, have never been produced by mineral synthesis (melting); alkali felspar cannot occur on account of the absence of adequate alkalies, and mellilite or gehlenite are always found in the place of anorthite and labradorite. Hence it follows that free sesqui-oxides and free silica are *ab initio* excluded as slag constituents in silicate slags.

As yet no melting-point curves for slags have been given, and indeed the statements as to the melting-points and temperatures of formation of slags are very scanty, as the following figures show:—

TABLE A.—*Temperature Determined by Princep Alloys.*

Material.	Temperature of Formation.	Melting-Point.
	° C.	° C.
Glass, plumbiferous	...	1000 (1400)
Glass, free from lead	...	1200
Ore slag from the Muldener Works, Freiberg	...	1030
Similar slag, rich in zinc oxide	...	1030
(Both these slags were full of blowholes on solidifying. They did not appear to become completely fluid until about 1130° C.)		
Copper regulus, "Concentration slag"	...	1045
Melaphyr from Mulatto	...	1106
Pechstein from Arran	...	1106
Hauyn-basalt from Neudorf near Annaberg	...	1080–1106
Leucite-basalt from Pöhlberg near Annaberg	...	1130
Syenite from Edle Krone near Tharandt	...	1130–1160
Pechstein porphyry from Leisnig	...	1130–1160
Quartz porphyry from the Travigno Valley	...	1130–1160
Asbestos	...	1300
Slag from the old Freiberg first fusion (in blast-furnaces)	...	1160–1170
Lead slags from the "Bleiarbeit" (1836)	...	1160
Pure tin slag from Altenberg	...	1160
Copper	...	1160
29·2 SiO_2 + 70·9 BaO	1444	...
37·6 SiO_2 + 62·4 BaO	1444	...
52·0 SiO_2 + 48·0 CaO	1444	...
61·8 SiO_2 + 38·2 CaO	1444	...
59·8 SiO_2 + 40·2 MgO	1444	...
69·0 SiO_2 + 31·0 MgO	1444	...
64·3 SiO_2 + 35·7 Al_2O_3	1444	...
73·0 SiO_2 + 27·0 Al_2O_3	1444	...
Blast-furnace slag:—SiO_2, 50; Al_2O_3, 17; FeO, 3; CaO, 30	1392	1208
Freiberg raw slag:—SiO_2, 48; Al_2O_3, 9; FeO, 37; CaO, 4·5; MgO, 1·5	1326	1166
Freiberg raw slag:—SiO_2, 50; Al_2O_3, 6; FeO, 38; CaO, 3; MgO, 1·5; BaO, 1·5	1344	1178
Freiberg lead slag:—SiO_2, 36·5; FeO, 40·5; Al_2O_3, 8·5; CaO, 4·0; MgO, 3·0; BaO, 7·5	1220	1160
Freiberg black copper slag:—SiO, 32·7; FeO, 60·3; Al_2O_3, 7·0—		
α Melted in an iron crucible	1273	1172
β Melted in a clay crucible	1220	1166
Raw slag from 3·45 dry ore and 5·85 lead slag	1267	1172
"Lead" slag from 2·34 roasted lead ore, 1·80 calcined coarse regular, 5·00 "lead slag," 0·30 coke powder	1208	1160
Almandine	...	1130–1160
Ordinary horneblende from Marienberg	...	1130
Basaltic horneblende from Luckow, near Teplitz	...	1166
Amphibole from the Ziller Valley	...	1385–1413
Adulare from St. Gotthardt	...	1400–1420
Bronzite from Kupferberg in Bohemia	...	1420–1436
Tourmaline-garnet from Mulatto, began to partially fuse at	...	1227
Tourmaline, showed still unfused particles at	...	1400
Mica porphyry from Knorre, began to melt at	...	1227
Mica porphyry, showed still unfused particles at	...	1452

TABLE B.—*Alumina-Lime Mono-Silicates. Temperatures of Melting-Points determined by Seger Fusion Mixtures.*[*]

No.	Silica.	Alumina.	Lime.	Temperature of Formation of the Slag.
				° C.
1	1·8762	...	3·4965	1570
2	,,	0·1071	3·3217	1526
3	,,	0·2141	3·1469	1492
4	,,	0·3212	2·9720	1468
5	,,	0·4283	2·7972	1451
6	,,	0·5353	2·6224	1439
7	,,	0·6424	2·4476	1430
8	,,	0·7495	2·2727	1422
9	,,	0·8565	2·0979	1417
10	,,	0·9639	1·9231	1412
11	,,	1·0707	1·7483	1410
12	,,	1·1777	1·5734	1430
13	,,	1·2848	1·3986	1468
14	,,	1·3918	1·2238	1526
15	,,	1·4989	1·0490	1613
16	,,	1·6060	0·8741	above 1671
17	,,	1·7130	0·6993	
18	,,	1·8201	0·5245	
19	,,	1·9272	0·3497	
20	,,	2·0342	0·1748	
21	,,	2·1413	...	

TABLE C.—*Alumina-Lime-Magnesia Mono-Silicates. Temperatures determined by Seger Fusion Cones.*[†]

No.	Silica.	Alumina.	Magnesia.	Lime.	Temperature of Formation of the Slag.
					° C.
11	1·8762	1·0707	...	1·7483	1410
22	,,	,,	0·1249	1·5734	1378
23	,,	,,	0·2497	1·3986	1365
24	,,	,,	0·3746	1·2238	1357
25	,,	,,	0·4994	1·0490	1352
25-A	,,	,,	0·5410	0·9907	1351
25-B	,,	,,	0·5826	0·9324	1350
26	,,	,,	0·6243	0·8741	1352
27	,,	,,	0·7491	0·6993	1359
28	,,	,,	0·8740	0·5245	1368
29	,,	,,	0·9988	0·3497	1381
30	,,	,,	1·1237	0·1748	1410
31	,,	,,	1·2485	...	1497

Paul Gredt calculates as follows all the other mono-silicates containing alumina, magnesia, and lime, as, for instance, the slag consisting of 1·8762 SiO_2 + 1·3918 Al_2O_3 + 0·3496 MgO + 0·7343

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[*] Paul Gredt, *Stahl und Eisen*, 1889, p. 756.

[†] *Ibid.*, p. 756.

CaO, which possesses the same composition as No. 14, except that as in slag No. 25 a portion of the lime has been replaced by magnesia:—

$$\frac{x}{1526 \text{ (No. 14)}} = \frac{1362 \text{ (No. 25)}}{1410 \text{ (No. 11)}}$$

$$x = 1463° \text{ C.}$$

TABLE D.—*Temperature of Formation and Fusion of Mono-Silicate Slags: (a) according to Paul Gredt; (b) as calculated by R. Åkerman.**

A.			B.					
					Fusion Temperature Calculated from these, taking the Assumed Specific Heats given.			
No.	Oxygen Ratio $\frac{Al_2O_3}{CaO}$.	Temperature of Formation of the Slag.	Oxygen Ratio $\frac{Al_2O_3}{CaO}$.	Total Heat of Fusion per Unit of Weight of Slag.	Assumed Specific Heat.	Fusion Temperature Calculated.	Assumed Specific Heat.†	Fusion Temperature Calculated.
		° C.		Calories.		° C.		° C.
1	0·00	1570	...	...	...	...	...	...
2	0·05	1526	...	...	...	...	...	...
3	0·11	1492	...	...	...	...	...	...
4	0·18	1468	...	...	...	...	...	...
...	...	...	0·20	428	0·30	1427	0·320	1338
5	0·25	1451	0·25	410	0·30	1367	0·312	1314
...	...	...	0·30	380	0·30	1267	0·305	1246
6	0·33	1439	...	...	...	...	...	...
...	...	...	0·40	363	0·30	1210	0·299	1215
7	0·43	1430	...	...	...	...	...	...
...	...	...	0·50	349	0·30	1163	0·291	1199
8	0·54	1422	...	...	...	...	...	...
9	0·67	1417	...	...	...	...	...	...
...	...	...	0·70	347	0·30	1157	0·290	1197
10	0·81	1412	...	...	...	...	...	...
...	...	...	0·90	355	0·30	1183	0·296	1200
11	1·00	1410	1·00	361	0·30	1203	0·299	1207
...	...	...	1·20	377	0·30	1257	0·305	1236
12	1·22	1430	...	...	...	...	...	...
13	1·50	1468	1·50	400	0·30	1333	0·310	1290
14	1·86	1526	...	...	...	...	...	...
...	...	...	2·00	430	0·30	1433	0·320	1344
15	2·33	1613	...	...	...	...	...	...
...	...	...	2·35	461	0·30	1537	0·327	1410

The total heat of fusion has happily been determined by R. Åkerman ‡ in the case of numerous slags. Even though these are not entirely proportional to the fusion temperatures, since the specific and latent heats of slags vary with their composition, yet these differences are not so great as to prevent the curves for heat of fusion as given by Åkerman being at least similar to the curves for the melting-points.

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* *Jernkontorets Annaler*, 1889, Nos. 5 and 6; *Stahl und Eisen*, 1890, p. 424.

† These specific heats are from observations by Åkerman, who found them to vary between 0·29 and 0·33, and to be less in the case of the more readily fusible slags than in the case of those which are less readily fusible.

‡ *Jernkontorets Annaler*, 1886, pp. 1-77; *Stahl und Eisen*, 1886, pp. 281 and 327.

Figs. 1 to 4 give the total heats of fusion of various silicates of lime or of lime and magnesia, from mono-silicates to the tri- or tetra-silicates. They resemble the well-known solidifying curves of solution. These curves give for each series of silicates two minima, &c.—

	1st Minimum.	2nd Minimum.
CaO Silicate . . .	1·5 Silicate	2·83 Silicate
(3 CaO+MgO) Silicate .	1·5 ,,	2·5 ,,
(2 CaO+MgO) ,, .	1·5 ,,	2·39 ,,
(CaO+MgO) ,, .	1·5 ,,	2·7 ,,

and three maxima, the middle one of which corresponds to—

In the CaO Silicate	1·87 Silicate
,, (3 CaO+MgO) Silicate . . .	1·76 ,,
,, (2 CaO+MgO) ,, . . .	1·78 ,,
,, (CaO+MgO) ,, . . .	1·76 ,,

Similar curves are shown in Figs. 5 and 6 for FeO silicates and lime-iron silicates, borrowed from H. O. Hofman.*

In this way we recognise one of the solution constituents, a meta-silicate, while the minima to the right and left of this maximum must correspond to the solidification points of eutectic mixtures.

It could be foreseen that meta-silicates would occur in slags, as this silica hydrate is even known in the free state. Besides, Vogt † has shown that quite a number of meta-silicates occur in slags such as enstatite, $MgSio_3$; hypersthene and bronzite $(FeMg)SiO_3$; wollastonite, $CaSiO_3$; augite, $Ca(MgFe)SiO_3$; rhodonite, $MnSiO_3$; babingtonite, $n(MnR)SiO_3 + Fe_2Si_3O_9$; and a new hexagonal lime silicate, $CaSiO_3$. Which, however, are the compounds that occur with these in the two eutectic mixtures? It cannot be free sesqui-oxide bases and free silica, since these, as we have seen, do not occur in slags. They must, therefore, be silicates. As the more basic compound, the ortho-silicate in the first instance is the more probable, as this silica, too, is known in the free state, and since Vogt has found these silicates also in slags:—Olivine, $(MgFe)_2SiO_4$; fayalite, $(MnFe)_2SiO_4$; tephroite, Mn_2SiO_4; monticellite, $CaMgSiO_4$; mellilite $(RO)_{12}(Al_2O_3)_2(SiO_2)_9$; and willemite, Zn_2SiO_4.

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* "The Temperatures at which certain Ferrous and Calcic Silicates are formed in Fusion." *Transactions of the American Institution of Mining Engineers*, September 1899.

† "Studien over Slaggen;" *Bilhang till K. Svenska Vet. akad. Handlingar*, vol. ix. No. I.; "Om Slaggers af Sammansättningen beroende Kristallisations förhållanden," *Jernkontorets Annaler*, 1885; "Beiträge zur Kentniss der Mineralbildung," Kristiana, 1892.

The question as to the acid constituents is much more difficult to answer, since Vogt only mentions a single acid silicate $(RO)_2(SiO_2)_3$, which occurs as globulites or crystallites in highly siliceous slags, in which the silica ratio equals at least 2·5 On the other hand, the heat of fusion curves of the lime silicates (Fig. 1, Plate XVIII.) go steadily up to the tetra-silicates without showing any pronounced maximum, so that at most there could only be a question as to the salts of the di-silicic acid, $H_2Si_2O_5$, or of the di-basic tri-silicic acid, $H_2Si_3O_7$. Finally, in slags with an oxygen-ratio of 0·8 to 0·5, Vogt has found a mineral, gehlenite, which corresponds to a 0·67 silicate.

We have thus as constituents of slags—

Silica Ratio.	Typical Formula.	Mineral.	Crystal System.
0·67	$\overset{''}{R}_3SiO_5$	Gehlenite $(RO)_3\,(Al_2O_3)\,(SiO_2)_2$ . . .	Tetragonal
1·00	$\overset{''}{R}_2SiO_4$	Mellilite $(RO)_{12}\,(Al_2O_3)_2\,(SiO_2)_9$ . . .	Tetradonal
		Olivine $(MgO)_2\,SiO_2$	Rhombic
		Fayalite $(FeO)_2\,SiO_2$	,,
		Tephroite $(MnO)_2\,SiO_2$	,,
		Monticellite $CaO\,MgO\,SiO_2$	,,
		Willemite $(ZnO)_2\,SiO_2$	,,
1·50	$\overset{''}{R}_4Si_3O_{10}$	New tetragonal mineral free from Al_2O_3 and rich in lime, Åkermanite $(R_4Si_3O_{10})$.	Tetragonal
2·00	$\overset{''}{R}SiO_3$	Hexagonal lime silicate, $CaO\,SiO_2$ . .	Hexagonal
		Enstatite, $MgO\,SiO_2$	Rhombic
		Hypersthene, Bronzite, } $(FeO)\,(MgO)\,SiO_2$. . .	,,
		Wollastonite, $CaO\,SiO_2$.	Monoclinic
		Augite varieties, $CaO\,(MgO)\,SiO_2$. . .	,,
		Rhodonite, $MnO\,SiO_2$	Triclinic
		Babingtonite, $(MnO\,RO)\,SiO_2+Fe_2O_3\,(SiO_2)_3$	,,
3·00 (?)	$\overset{''}{R}_2Si_3O_8$	Globulites in acid slags	?
4·00	$\overset{''}{R}Si_2O_5$	?	?
6·00	$\overset{''}{R}Si_3O_7$	?	?

The last three members of the series are more or less hypothetical.

It now only remains to point out in what way the occurrence of the above-mentioned minerals is connected with the composition of the slags, in doing which the investigations of J. H. L. Vogt have chiefly to be considered. He says in this connection: "A comparative study of the analyses showed that the formation of minerals in the molten mass distinctly depends principally on the average chemical composition. The minerals result as products of the action, chemical affinity, and inter-reactions of the principal constituents—in other words, the formation of minerals depends upon chemical mass action. The different kinds of physical influence which are possible in the formation of slags exert only a small secondary influence on the formation of minerals if a certain minimum limit of time* for crystallisation is not exceeded."

In the highly siliceous enamel slags (2·5 silicates and those still more acid), Vogt states that globulites and crystallites of a silicate occur, which is possibly represented by the formula $(RO)_2(SiO_2)_3 - RO = CaO$ and MgO. From the bi-silicate slags enstatite crystallises out if the fused mass contains more MgO (+FeO), as compared to CaO (+MnO), than is shown by the molecular ratios 2·44 MgO : 1 CaO. On the other hand, augite crystallises out if more CaO is present than 1·40 MgO : 1 CaO. If the contents of lime exceed the limit 0·3 MgO : 1 CaO, wollastonite or the new hexagonal lime silicate crystallises out, the former probably from the fused masses richer in silica, and the latter from those poorer in silica. Rhodonite forms in bi-silicate masses if more MnO is present in proportion to RO (= CaO, MgO, FeO) than 1 MnO = 0·9 RO. On the other hand, augite separates when there is a lesser manganese ratio than 1 MnO : 7 RO. With an average MnO contents, when, for instance, there is 1 MnO : 1·82 RO, rhodonite and augite may form simultaneously.

In fused masses whose composition approximates to that of mono-silicates, olivine always forms if there is more RO (= MgO,

---

* This is only a few minutes, at most five to seven, in the case of minerals free from alumina, as, for instance, the new tetragonal mineral, provided alumina is not present in the fused mass. For alumina minerals, on the other hand, in fused masses rich in alumina the time may be from several hours to several days.

MnO, FeO), as compared with CaO (in addition to Na_2O, K_2O), than 1 RO : 1·10 to 1·20 CaO. (The first limit corresponds to a larger percentage of alumina, say 20, and the latter for a lower percentage of alumina, say 3.)

Mellilite or one of the other tetragonal minerals forms, on the other hand, if there is a larger percentage of CaO than 1 RO : 1·25 to 1·30 CaO. (The limit varies with the percentage of alumina.) In the intervals between the above-named limits both the proximate minerals may form.

The pyroxene group of minerals and the hexagonal lime silicate only separate out in a fused mass, which contains more silica than corresponds to the oxygen ratio $\frac{\text{Acid oxygen}}{\text{Basic oxygen}} = 1{\cdot}50$ to 1·60, alumina being reckoned as a base. The boundary between slags which contain the hexagonal lime silicate and one of the tetragonal minerals appears to be distinct at about the degree of silicification, 1·42 to 1·45. The limit between the augite slags and those which contain tetragonal minerals is at about the degree of silification 1·50 to 1·53, and that between the augite and enstatite slags and the olivin slags at 1·5. The presence of more or less alumina appears to only very slightly affect the above limits.

In the tetragonal group the new member relatively rich in silica and lime (Åkermanite), only forms between the oxygen ratios 1·35 and 1·50, and probably only when little alumina is present. Gehlenite is only formed in fused masses, which are at the same time rich in alumina and strongly basic—less than 0·8 silicate. The true mellilite lies in the interval between the two.

It may be as well also to mention still more basic slags, although they really belong to the oxide series.

Finery slags consist of fayalite, magnetite, and an excess of FeO. As a rule, the very basic slags are characterised by sesquioxide compounds. Thus, for instance, spinell $RO.R_2O_3$, which always crystallises out before the silicate minerals, only occurs with very low silica percentages (up to mono-silicate) and relatively high percentages of alumina and silica. Spinell contains partly magnesia only and partly also lime. Zinc spinell forms more readily than magnesia spinell. In fused materials which contain both FeO and Fe_2O_3, magnetite ($FeO.Fe_2O_3$) forms very readily even if the slag contains silica, though it must not be more acid than a bi-silicate. In slags containing spinell, the separation of the magnetite takes place after the spinell, but before or simultaneously with the separation of the silicate minerals. Ferric oxide also readily enters into combination with other compounds. According to the investigations of L. Bourgeois, MnO can readily combine with Al_2O_3 and Mn_2O_3.

An excess of Al_2O_3 disturbs the crystallisation process when the cooling is very rapid, though possibly not in the case of very basic masses. It consequently tends to render slags glassy. Sulphur always occurs in slags as monosulphide crystals of the cubic system, such as CaS, MnS, FeS, and isomorphic mixtures. In very basic enamel slags these compounds occur as globulites. In very basic slags sesquioxide compounds appear, therefore, to predominate, in addition to R.O bases.

By means of the diagram (Fig. 7, Plate XIX.) an approximate calculation of the composition of slags may be made. One calculates in the first place the ratio of the oxygen contents of the silica as well as of the total bases, with exception of Cu_2O which appears to have scarcely no affinity for silica. From the sum of the latter the half of the sulphur contents is deducted, corresponding to the oxygen equivalent of the RS, and then from this is calculated the ratio $\frac{\text{Acid oxygen}}{\text{Basic oxygen}}$. The composition of the slags can then be judged approximately, that is to say, the constituents present in the slags can be ascertained in this way. If the oxygen ratio exceed 2·0, the slags consist of the silicates $RSiO_3$, and probably $R_2Si_3O_8$, or, written otherwise, $RO.SiO_2$ and $(RO)_2(SiO_2)_3$. The composition of the slags can then be expressed by the formula

$$xRO.SiO_2 + y(RO)_2(SiO_2)_3$$

If s represents the oxygen contents of the silica and b that of the bases, then—

$$2x + 6y = s$$
$$x + 2y = b,$$

whence

$$y = \frac{s}{2} - b$$

and

$$x = 3b - s$$

The following is an example: Let the following represent the composition of the slag:—

	Per Cent.		Per Cent.	
SiO_2	61·16	containing oxygen	= 32·62 = s	
Al_2O_3	4·43	,, ,,	= 2·05	= 13·07 = b
CaO	22·83	,, ,,	= 6·52	
MgO	10·25	,, ,,	= 4·10	
MnO	0·49	,, ,,	= 0·11	
FeO	1·28	,, ,,	= 0·28	
Total	100·44			

$$\frac{\text{Acid oxygen}}{\text{Basic oxygen}}=\frac{32{\cdot}62}{13{\cdot}07}=2{\cdot}49$$

$$y=\frac{s}{2}-b=16{\cdot}31-13{\cdot}07=3{\cdot}24$$

$$x=3b-s=39{\cdot}21-32{\cdot}62=6{\cdot}59$$

whence we obtain the slag composition =

$$6{\cdot}59\,RO.SiO_2+3{\cdot}24(RO)_2(SiO_2)_3$$

In exactly a similar manner we obtain the following composition of a slag lying between the bi- and mono-silicate:—

$$xRSiO_3+yR_2SiO_4,\ \text{or}\ xRO.SiO_2+y(RO)_2SiO_2$$

Further—

$$2x+2y=s$$
$$x+2y=b$$

whence

$$x=s-b$$
$$y=b-\frac{s}{2}$$

Example:—The slag composition is—

	Per Cent.		Per Cent.	
SiO_2	47·87	containing oxygen	= 25·53 = s	
Al_2O_3	5·37	,, ,,	= 2·50	= 16·64 = b
CaO	37·76	,, ,,	= 10·79	
MgO	7·78	,, ,,	= 3·11	
MnO	0·37	,, ,,	= 0·08	
FeO	0·72	,, ,,	= 0·16	
Total	99·87			

$$\frac{\text{Acid oxygen}}{\text{Basic oxygen}}=\frac{25{\cdot}63}{16{\cdot}64}=1{\cdot}53$$

$$x=s-b=25{\cdot}53-16{\cdot}64=8{\cdot}89$$

$$y=b=\frac{s}{2}=16{\cdot}64-12{\cdot}76=3{\cdot}88$$

and consequently the composition is

$$8{\cdot}89\ RSiO_3+3{\cdot}88\ R_2SiO_4$$

In slags with an oxygen ratio of less than one, and a high percentage of magnesia and alumina, and in bi-silicate slags with ferric oxide contents, there is another kind of calculation which shall be referred to later on. If the oxygen ratio lies between 1·0 and 0·5, and if for 1 CaO there is not more than 0·7 MgO + MnO + FeO, then one has—

$$x(RO)_{3}.SiO_2+y(RO)_2.SiO_2$$

and thence

$$2x+2y=s$$
$$3x+2y=b$$

whence

$$x=b-s$$
$$y=\frac{3}{2}s-b$$

EXAMPLE :—The slag contains—

	Per Cent.		Per Cent.	
SiO_2	28·32	containing oxygen	$=15{\cdot}10=s$	
Al_2O_3	24·24	,, ,,	=11·30	$=23{\cdot}96=b$
CaO	40·12	,, ,,	=11·46	
MgO	2·79	,, ,,	= 1·12	
MnO	0·07	,, ,,	= 0·02	
FeO	0·27	,, ,,	= 0·06	
CaS	3·38	,, ,,	= ...	

$$\frac{\text{Acid oxygen}}{\text{Basic oxygen}}=\frac{15{\cdot}10}{23{\cdot}96}=0{\cdot}63$$

$$x=b-s=23{\cdot}96-15{\cdot}10=8{\cdot}86$$

$$y=\frac{3}{2}s-b=22{\cdot}65-23{\cdot}96=-1{\cdot}31$$

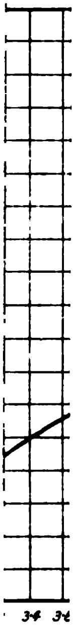
We thus obtain for y a value which, though small, is a negative one and impossible, but which still shows that the slag consists chiefly of gehlenite, but must in addition contain some spinell. The quantity of this spinell ($RO.Al_2O_3$) can be calculated in the following manner:—

The above slag can only consist of gehlenite and spinell. If the basic oxygen in gehlenite is called b_1, then evidently $\frac{s}{b_1}=0{\cdot}67$, and from this the basic oxygen of the gehlenite can be calculated to be—

$$b_1=\frac{s}{0{\cdot}67}=\frac{15{\cdot}10}{0{\cdot}67}=22{\cdot}53$$

The oxygen contents of the spinell are consequently—

$$b-b_1=23{\cdot}96-22{\cdot}53=1{\cdot}43$$



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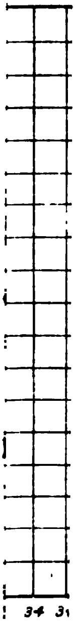

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and since this mineral ($RO.Al_2O_3$) contains four atoms of oxygen in the molecule—

$$\text{Spinell } (RO.Al_2O_3) = \frac{b - b_1}{4} = 0{\cdot}35$$

while for gehlenite one finds

$$x = \frac{s}{2} = 7{\cdot}55$$

The composition of the slag is consequently

$$7{\cdot}55\,(RO)_2.SiO_2 + 0{\cdot}35\,RO.Al_2O_3.$$

With an oxygen ratio of less than 1, and if for each 1 CaO there is more than 0·7 ($MgO + MnO + FeO$), we have to do with a mixture of olivine and spinell, and have therefore:—

$$x(RO)_2.SiO_2 + yRO.Al_2O_3$$

and further—

$$2x = s$$
$$2x + 4y = b$$

hence—

$$x = \frac{s}{2}$$

$$y = \frac{b - s}{4}$$

Example:—The slag contains—

	Per Cent.		Per Cent.	
SiO_2	24·40	containing oxygen	=13·00=s	
Al_2O_3	4·90	,, ,,	= 2·30	=17·37=b
CaO	0·53	,, ,,	= 0·15	
MgO	trace	,, ,,	=trace	
MnO	0·13	,, ,,	= 0·04	
FeO	66·94	,, ,,	=14·88	

$$\frac{\text{Acid oxygen}}{\text{Basic oxygen}} = 0{\cdot}75$$

$$x = \frac{s}{2} = \frac{13{\cdot}00}{2} = 6{\cdot}50$$

$$y = \frac{b - s}{4} = \frac{17{\cdot}37 - 13{\cdot}00}{4} = \frac{4{\cdot}37}{4} = 1{\cdot}09$$

and the composition of the slag is:—

$$6{\cdot}50\,(RO)_2.SiO_2 + 1{\cdot}09\,RO.Al_2O_3$$

One sees that in slags the contents of spinell can be calculated, at least approximately, if the oxygen ratio is less than that which corresponds to a mono-silicate. In a more acid slag, on the other hand, any spinell which may be present can only be determined by analytical methods. It must be particularly pointed out, however, that the calculation does not give only the $RO.Al_2O_3$, but also $RO.Fe_2O_3$ and $RO.Mn_2O_3$. Spinell consists of RO (with 1 of oxygen) and Al_2O_3 (with 3 atoms of oxygen). The 1·09 molecule of spinell calculated above must therefore contain $3 \times 1{\cdot}09 = 3{\cdot}27$ molecules of Al_2O_3, while as a fact only 2·30 Al_2O_3 are present. The slags can consequently contain only $\frac{2{\cdot}30}{3} = 0{\cdot}77$ of spinell, whilst the remaining oxygen of the base namely, $17{\cdot}37 - 13{\cdot}00 - 4 \times 0{\cdot}77 = 17{\cdot}37 - 16{\cdot}08 = 1{\cdot}29$, must be in the form of free RO bases. The corrected composition of the slag is thus found to be $6{\cdot}50\ (RO)_2\ SiO_2 + 0{\cdot}77\ RO\ Al_2O_3 + 1{\cdot}29$ RO.

From the paper by J. H. L. Vogt are taken the results of a series of investigations as to the spinell contents of a number of slags, which are now given to show how the results as to the percentage of spinell present obtained by calculation agree with the values which which were found direct.

Analyses of Blast-Furnace Slags by Muirhead. *

Constituents.	No. 128.	No. 129.	No. 130.	No. 131.	No. 132.	No. 133.
	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.
Silica	24·92	28·74	27·01	26·46	27·53	27·64
Alumina	23·47	25·63	20·13	23·44	22·23	22·93
Lime	37·32	29·40	40·93	35·50	36·30	37·06
Magnesia	13·23	13·75	11·09	13·34	13·00	12·95
Totals	98·94	97·52	99·16	98·74†	99·06	100·58
Spinell	17·40	17·88	10·82	8·18	6·07	9·04
Oxygen in Silica	13·12	15·16	14·41	14·11	14·69	14·75
Oxygen in Alumina	10·94	11·94	9·38	10·92	10·37	10·69
Oxygen in Lime	10·66	8·40	11·69	10·16	10·37	10·59
Oxygen in Magnesia	5·29	5·50	4·44	5·34	5·20	5·18
$\frac{\text{Acid oxygen}}{\text{Basic oxygen}}$	0·49	0·59	0·56	0·54	0·57	0·56
$\frac{\text{MgO oxygen}}{\text{CaO oxygen}}$	0·49	0·65	0·37	0·52	0·50	0·49

* *Iron*, October 15, 1880.

† 99·78 in original.

The above-mentioned slags can consequently contain only gehlenite and spinell. The following shows the composition of that portion of the slag which was soluble in hydrochloric and hydrofluoric acids:—

	No. 128.	No. 129.	No. 130.	No. 131.	No. 132.	No. 133.
	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.
Silica	24·92	28·74	27·01	26·46	27·53	27·64
Alumina	11·62	13·46	13·00	17·80	18·06	16·24
Lime	35·84	27·72	39·30	35·50	36·30	37·06
Magnesia	9·16	9·70	9·00	10·80	11·10	10·10
Totals . .	81·54	79·62	88·31	90·56	92·99	91·54
Aluminate	17·40	17·88	10·82	8·18	6·07	9·04
Totals . .	98·94	97·50	99·13	98·74	99·06	100·58

Composition of the Aluminates.

	Constituents.	No. 128.	No. 129.	No. 130.	No. 131.	No. 132.	No. 133.
		Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.
For 100 parts of Slag.	Alumina	11·85	12·17	7·13	5·64	4·17	6·69
	Lime	1·48	1·68	1·63	...	...	...
	Magnesia	4·07	4·05	2·09	2·54	1·90	2·35
	Totals . .	17·40	17·90*	10·85*	8·18	6·07	9·04
For 100 parts Aluminate.	Al_2O_3	68·11	69·98	65·88	68·92	68·72	74·00
	CaO	8·48	9·39	14·96	...	...	...
	MgO	23·41	22·63	19·16	31·08	31·28	26·00
	Totals . .	100·00	100·00	100·00	100·00	100·00	100·00
Oxygen in	Al_2O_3	5·57	5·72	3·35	2·65	1·96	3·14
	CaO	0·42	0·48	0·47	...	...	...
	MgO	1·63	1·62	0·84	1·02	0·76	0·94
	RO bases	2·05	2·10	1·31	1·02	0·76	0·94
$\frac{Al_2O_3 \text{ oxygen}}{RO \text{ oxygen}}$		2·71	2·72	2·56	2·59	2·58	3·34

As spinell possesses the oxygen ratio 3 : 1, it is evident that in the case of the above analyses we have not to deal with pure aluminates.

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* These do not actually agree with the quantities found direct.

The following table shows the composition of the slags as calculated by means of the formulæ already given:—

	No. 128.	No. 129.	No. 130.	No. 131.	No. 132.	No. 133.
Gehlenite	6·56	7·58	7·21	7·06	7·35	7·38
Spinell	1·83	0·80	1·00	1·32	1·00	1·11
Oxygen in spinell Al_2O_3	5·49	2·42	3·00	3·96	3·02	3·33
Oxygen in spinell RO	1·83	0·80	1·00	1·32	1·00	1·11

If these numbers are compared with those that are obtained direct, it is found that—

(*a*) By calculation, a smaller percentage of RO Al_2O_3 is always found in the case of aluminates containing lime.

(*β*) When the aluminates are free from lime, calculation shows a larger percentage of RO Al_2O_3 than results from direct determination.

The latter might be explained by the partial decomposition of the $MgO.Al_2O_3$, but the former is only explainable by inclusions in spinell.

For the approximate determination of the spinell, J. H. L. Vogt [*] has given the following empiric formula:—

$$\text{Spinell} = c(1-\alpha)\beta(\beta-4)\gamma(\gamma-8)$$

in which a is the oxygen ratio $\frac{s}{b}$, Al_2O_3 being calculated as a base. β and γ are the percentage contents of MgO and Al_2O_3, while c is a constant, and about equal to $\frac{1}{1200}$. This gives, however, somewhat inaccurate results, as even the figures given by Vogt show:—

Calculated.	Found.	Calculated.	Found.
Ca 20 . . .	17·68	Ca 13 . .	6·07
„ 17 . . .	17·40	„ 3 . .	Ca 6·5
„ 7 . . .	10·82	„ 4·5 . . .	„ 3
„ 13 . . .	9·04	„ 12 . . .	„ 2
„ 13 . . .	8·18	„ 0·5 . . .	„ 0·5

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[*] See *Bihang till K. Svenska Vet akad. Handlingar*, vol. ix. No. I. p. 161.

The following table gives a general view of the equations used in the slag calculations :—

Chemical Composition of the Slag Constituents.		$(RO)_2.(SiO_2)_3$	$RO.SiO_2$	$(RO)_2.SiO_2$	$(RO)_3.SiO_2$	$RO.R_2O_3$
	Oxygen Ratio in Mineral.	3 : 1	2 : 1	1 : 1	2 : 3	...
$\frac{s}{b}$	Minerals corresponding	Globulites in acid enamel slags	Hexagonal lime silicate, $CaSiO_3$ Wollastonite, $CaSiO_3$ Augite, $Ca(Mg)SiO_3$ Rhodonite, $MnSiO_3$ Babingtonite, $n(MnR)SiO_3+Fe_2Si_3O_9$ Enstatite, $MgSiO_3$ Hypersthene, Bronzite, $Fe(Mg)SiO_3$	Olivine, Mg_2SiO_4 Fayalite, Fe_2SiO_4 Tephroite, Mn_2SiO_4 Monticellite, $Ca_2SiO_4+Mg_2SiO_4$ Willemite, Zn_2SiO_4 Mellilite, $(RO)_{12}(Al_2O_3)_2(SiO_2)_9$ New tetragonal mineral,* Åkermanite $(R_4Si_3O_{10})$	Gehlenite, $(RO)_3.Al_2O_3.(SiO_2)_2$	Spinell, $RO.Al_2O_3$ Magnetite, $RO.Fe_2O_3$, &c.
>2·00	...	$\frac{s}{2}-b$	$3b-s$	...	...	...
2·00 to 1·00	...	...	$s-b$	$b-\frac{s}{2}$	...	...
1·00 to 0·67	More CaO than CaO=0·7(MgO+MnO+FeO)	...	...	$\frac{3}{2}s-b$	$b-s$	...
<0·67	Do.	...	...	...	$\frac{s}{2}$	$\frac{1}{4}\left(b-\frac{s}{0{\cdot}67}\right)$
<1·00	Less CaO than CaO=0·7(Mg+MnO+FeO)	...	...	$\frac{s}{2}$	...	$\frac{1}{4}(b-s)$

There now only remains to be determined the limits between the minerals belonging to one and the same degree of silicification, a matter which may be of importance in many metallurgical processes. To obtain as good a general view as possible, we will place these on Vogt's data in the following table:—

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* Oxygen ratio=1·50. This mineral, whose degree of silicification occupies the mean between a bi-silicate and a mono-silicate, appears to take the place of a eutectic mixture. In calculating slag compositions no notice is taken of it.

		Wollastonite.	Hexagonal Lime Silicate.	Augite.	Rhodonite.	Enstatite (Hypersthene).
Bi-silicates.	$(MgO+MnO+FeO):CaO$	$<0·25$		0·50 to 1·40		$>2·40$
	$(CaO+MgO+FeO):MnO$	...	...	$>3–4$	$<0·9$ to 1·0	...
	CaO	Paramount		...	...	Little
	MgO	Little		...	...	Paramount
	FeO	...	...	...	Little	
	MnO	...	...	...	Paramount	...
		New Tetragonal mineral free from Al_2O_3 Åkermanite		Mellilite	Gehlenite	Olivine
Mono-silicates and more basic silicates.	$CaO:(MgO+MnO+FeO)$ Al_2O_3	$>1·10$ to 1·20 : 1 3 per cent. to 5 per cent.				$<1·10$ to 1·20 : 1
	$CaO:(MgO+MnO+FeO)$ Al_2O_3	$>1·1:1$ Higher than the above				$<1·1:1$
	$CaO:(MgO+MnO+FeO)$ Al_2O_3	Still somewhat higher than 1·20 : 1 Less than 3 per cent.				Somewhat less
	$s:b$	1·30 to 1·50		1·30 to 0·80	$<8·80$	$<1·50$

About and between the boundaries of two adjacent mineral areas both minerals can occur together.

G. Hilgenstock* assumes that in slags the silicate $RO.SiO_2$ exists. He observes in this connection:—"Our blast-furnace slag, as we try to get it from the general average of the materials we have to deal with, we calculate in general from the formula $(RO)_2.SiO_2$, and measure according to that the lime to be added, since we know that a silicate slag in which the sum of the oxygen of the bases is equal to the oxygen of the silica, taken on the whole, possesses an adequate degree of fusibility. That is to say, it is adequately fluid at a definite temperature, and it does not matter to us that such a slag contains considerable quantities of 'free lime' merely 'dissolved.' If, however, in consequence of a change in the materials at the same blast-furnace temperature, and with an otherwise similar composition of the slag, the percentage power of solubility for free lime is exceeded, which becomes evident if the thick-fluid slag soon solidifies and decomposes, then if anything like an appearance of a want of lime is observable, the addition of lime is rapidly increased, and consequently also the percentage of 'free lime' in the slag, though it may be that we shall afterwards find that RO in the thick fluid decomposing slag was less than in that which at the same temperature was adequately fluid. I have only been able to explain various facts noticeable in the behaviour of molten blast-furnace slags by the solubility for free lime. The contents of free lime shows that in the case of our lime-basic blast-furnace slags there can be no question of a compound R_2SiO_4, even though their constituents approximate to the formula $(RO)_2SiO_2$.

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* *Loc. cit.*

"In the case of a slag containing—

Silica	34·18
Ferrous oxide	1·14
Manganous oxide	3·93
Lime	39·26
Alumina	16·73
Magnesia	2·32
Calcium sulphide	4·23

if as much of the lime as possible is extracted by means of a suitable sugar solution, one obtains for 39 SiO_2 37 CaO, whence it follows that the quantities approximate sufficiently accurately to the equivalents, and that the silicate of our lime-basic blast-furnace slags is the lime silicate $CaO.SiO_2$, and further, that it is of the type of carbonic acid, being derivable from the acid H_2SiO_3."

This view of Hilgenstock's is contrary to that derived from microscopic examination, and it therefore becomes necessary to examine whether his views are accurate or not. In the first place, the existence of the meta-silicic acid, as well as of the ortho-acid, is known with certainty, since there are not only numerous silicates corresponding to it, but the free acid itself is also known. It appears, therefore, to be at least very probable that the slags may contain ortho-silicate. On the other hand, the conclusion that in slags the silica can only be combined with lime appears very doubtful, as numerous distinctly defined double silicates are well known, and therefore the possibility of the formation of other silicates can at least not be disputed. It may at once be admitted that the silica shows greater combining power for lime than for ferrous oxide, manganous oxide, alumina, &c., but in accordance with the laws of masses, it is certain that, in the presence of all these bases, silica must be combined not only with lime, but with all these bases (in accordance, on the one hand, with the relative degrees of affinity, and on the other with the mass ratios). The other bases can consequently certainly not be disregarded. If for the above-mentioned slag the oxygen ratio is calculated, one obtains—

	Per Cent.		Per Cent.	
Silica	34·18	containing oxygen =	18·21 = *s*	
Ferrous oxide	1·14	„ „	0·25	= 21·14 = *b*
Manganous oxide	3·93	„ „	0·87	
Lime	39·26	„ „	11·22	
Alumina	16·73	„ „	7·87	
Magnesia	2·32	„ „	0·93	
Calcium sulphide	4·23	„ „	...	

$$\frac{\text{Acid oxygen}}{\text{Basic oxygen}}=0{\cdot}86$$

According to Hilgenstock's view, the slag must contain a silicate of the composition—

	Per Cent.		Per Cent.
SiO_2	34·18	containing oxygen =	18·21
CaO	31·61	„ „	9·11
	65·79		

in which are dissolved—

	Per Cent.		Per Cent.	
Free lime	7·65	containing oxygen =	2·11	= 12·03
Ferrous oxide	1·14	„ „	0·25	
Manganous oxide	3·93	„ „	0·87	
Magnesia	2·32	„ „	0·93	
Alumina	16·73	„ „	7·87	
Calcium sulphide	4·23	„ „	...	

while according to the formula above stated the composition of the slag would be :—

$$8{\cdot}17(RO)_2.SiO_2+2{\cdot}92(RO)_3.SiO_2$$

the possibility of the formation of sesqui-oxides being left out of the question.

According to Hilgenstock, the residue insoluble in the sugar solution contains—

39 silica, containing oxygen = 19·61
37 lime, ,, ,, 10·57

whence it follows that it is a bi-silicate, which for 19·61 acid oxygen should have 9·80 basic oxygen. Twenty-four per cent. is wanting, however, by Hilgenstock's method. If one assumes that the 39 per cent. of silica of the residue corresponds exactly to the 34·18 per cent. of the slag, and that all the other slag constituents remain in the residue, with the exception of the lime soluble in the sugar solution, then its composition is—

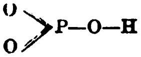
	Per Cent.		Per Cent.	
SiO_2	39·00	containing oxygen =	19·61	
CaO	37·00	,, ,,	10·57	= 22·25
FeO	1·30	,, ,,	0·37	
MnO	4·48	,, ,,	1·28	
Al_2O_3	19·09	,, ,,	8·98	
MgO	2·64	,, ,,	1·05	
CaS	4·84	,, ,,	...	
	108·35			

The above analysis gives, however, 108·35. Something else must, therefore, have gone into the solution. Deducting first the 4·84 of CaS, which must certainly have been decomposed and dissolved, there remains 103·51. If one further assumes, as is not improbable in the above slag, owing to its high percentage of alumina and the oxygen ratios, that the magnesia was present as aluminate, that this was decomposed by the sugar solution, and that the magnesia, too, passed into solution, then the total becomes 100·87, and one obtains for 19·61 acid oxygen 21·20 basic oxygen. In this way we get the oxygen ratio 1 : 1, corresponding very closely to the silicate $(RO)_2.SiO_2$. One can therefore explain the behaviour of the above slag as described by Hilgenstock, either by considering the compound $(RO)_3SiO_2$—gehlenite—as a solution of RO in $(RO)_2.SiO_2$, or by assuming that the compound $(RO)_3.SiO_2$ was decomposed by the sugar solution into $(RO)_2.SiO_2$ and RO.

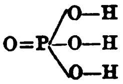
II.—PHOSPHATE SLAGS.

In this case, too, we will first consider the various phosphoric acids so far as they are yet known. These are as follows:—

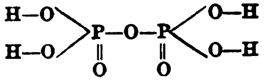
2. **Basic or *meta* phosphoric acid=H_2PO_3** or



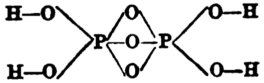
3. **Basic or *ortho* phosphoric acid=H_3PO_4** or



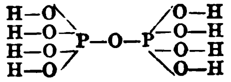
4. **Basic or *pyro* phosphoric acid=$H_4P_2O_7$** or



or



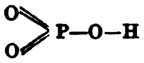
8. **Basic (pyro) phosphoric acid=$H_8P_2O_9$*** or



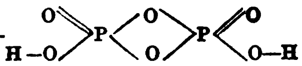
Of this latter acid there is only known the tetra calcium phosphate occurring in basic slag and Wiborgh's phosphate, $Ca_3Na_2H_2O_9$.

From meta phosphoric acid the following polymeres are derivable:—

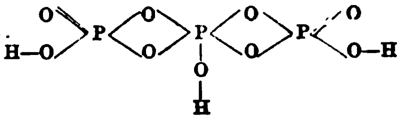
Meta phosphoric acid—



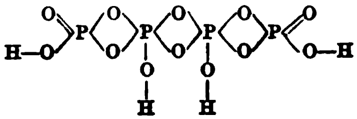
Di-meta phosphoric acid—



Tri-meta phosphoric acid—



Tetra-meta phosphoric acid—



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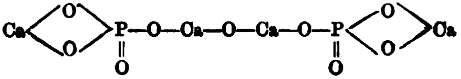
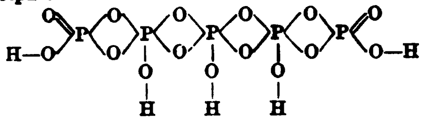
* Kosmann assumes for the constitution of calcium phosphate the formula—

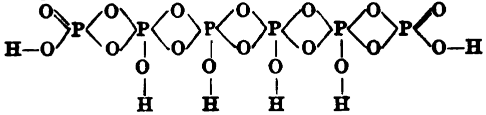


Penta-meta phosphoric acid—



(This latter has not yet been produced).

Hexa-meta phosphoric acid—



G. Hilgenstock [*] was the first to show that the phosphoric acid occurred in basic slag as tetra-basic lime phosphate ($4CaO.P_2O_5 = Ca_4P_2O_9$). Stead and Ridsdale [†] showed the presence of the following crystalline substances in the basic Bessemer slag of the North-Eastern Company :—

(1.) Large well-formed crystals of $(CaO)_4P_2O_5$.

(2.) Blue crystals of the compound $CaOP_2O_5.CaOSiO_2$.

(3.) Feather-shaped crystals, which contained some 86 per cent. of basic oxides, chiefly of Ca, Mg, Fe as Fe_2O_3 and FeO, and Mn, with less than 4 per cent. of acid oxides.

(4.) Hexagonal crystals, which contained about 86 per cent. of $(CaO)_4P_2O_5$, and 10 to 11 per cent. of silicates of metallic oxides.

(5.) Black magnetic needles, consisting of 10 per cent. of $CaOAl_2O_3$, 45 per cent. of $(CaO)_3Fe_3O_4$, and 35·5 per cent. of $(CaO)_3Fe_2O_3$.

(6.) Non-magnetic black crystals, containing 15 per cent. of $CaOAl_2O_3$, and 73 per cent. of $(CaO)_3Fe_2O_3$.

Subsequently G. Hilgenstock [†] succeeded in producing the true compound in acicular form, which resembled the hexagonal prisms of basic slag. This he did by melting together calcium tri-phosphate, or calcium phosphate and phosphorus pent-oxide, with suitable quantities of quicklime, a little fluorspar being added. These crystals had on the average the following composition :—

---

[*] *Stahl und Eisen*, 1886, No. II.

[†] *Journal of the Iron and Steel Institute*, 1887, No. I. p. 222.

[‡] *Stahl und Eisen*, 1887, p. 557.

	Per Cent.
P_2O_5	38·51
CaO	60·08
SiO_2	0·10

They were all colourless, and contained less inclusions than those derived from basic slag, these latter constantly appearing opaque or coloured brown by metallic oxides.

In basic slags the phosphate occurs, it is true, in hexagonal prisms, but chiefly in the tabular form of the rhombic system, as well as in small bright blue crystals with a diamond-like lustre, which, according to Bücking * and Linck, are monoclinic. The order in which these separate out is the following:—

(1.) Rhombic tabular crystals. These separate out at the highest temperatures reached.

(2.) Hexagonal prisms (acicular crystals). These separate from the solution, now poorer in phosphoric acid, at a lower temperature.

(3.) Blue lustrous monoclinic crystals. These separate out still later than the above. With the latter crystals appear black fern-like acicular groupings of a substance which, according to Stead and Ridsdale,† consists of calcium ferrate and calcium aluminate.

This probably explains, too, how it was that in the crucible experiments, in which the temperature of the converter is far from being attainable, no rhombic tabular crystals were produced.

The crystals of the "tetra-basic" calcium phosphate show, without exception, considerable quantities of inclusions of foreign substances, as is shown by the following analyses:—

A.—*Hexagonal Prisms.*

Constituents.	G. Hilgenstock.	Stead.	Bücking and Linke.
	Per Cent.	Per Cent.	Per Cent.
P_2O_5	34·94	33·707	36·77
CaO	57·55	53·536	53·51
MgO	...	0·486	0·40
Fe_2O_3	...	4·857	1·78
FeO	4·00	1·286	2·22
MnO	...	0·790	...
VO	...	1·343	...
SiO_2	3·24	3·900	3·81
S	...	0·460	trace
Cl	...	...	trace
Al_2O_3	...	...	1·09

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* *Stahl und Eisen*, 1887, p. 245.

† *Loc. cit.*

B.—*Tabular Rhombic Crystals.*

(According to Bücking and Linke.)

	Per Cent.
P_2O_5	38·77
CaO	59·53
MgO	trace
$Fe_2O_3+Al_2O_3$	0·89
MnO	strong trace
SiO_2	0·89
S	0·28
Total	100·36

C.—*Blue Monoclinic Crystals.*

Constituents.	G. Hilgenstock.	Stead.	Bücking and Linke.
	Per Cent.	Per Cent.	Per Cent.
P_2O_5	30·85	29·146	31·19
CaO	57·60	56·578	57·42
MgO	...	0·738	trace
Fe_2O_3	...	1·000	...
Al_2O_3	...	trace	1·18
FeO	2·94	...	0·95
MnO	...	0·210	trace
SiO_2	9·42	10·791	9·47
S	...	0·055	trace

All these analyses correspond with the formula $Ca_4P_2O_9$, and show that the crystals contain somewhat variably composed inclusions. In this connection mention must be made of the so-called backwardation of the phosphoric acid, that is to say, the gradual trend to insolubility of the phosphoric acid soluble in citric acid. O. Förster * found that if $Ca_4P_2O_9$ is heated for a short time to a temperature of some hundred degrees below its temperature of formation, it undergoes a change, a large part of the phosphoric acid which was soluble in phosphoric acid becoming insoluble. The insoluble residues proved to be $(Ca_3P_2O_8)_3CaO$, and if a slight quantity of silica was present, then they were $(Ca_3P_2O_8)_3.CaSiO_3$. While this change is a very far-reaching one in tetra-calcium phosphate, in the case of basic slag only a relatively small portion of the phosphate is affected. Ignition in hydrogen brings about the same change as ignition in air, only in a less degree. In the latter case no doubt the carbon dioxide produced in the blowpipe flame exerts an influence as well as the ordinary action of the oxygen of the air on other constituents contained in the basic slag. Probably there is produced at the same time $CaO.FeO$ or $CaO.Fe_2O_3$. FeS and $MnO.Fe_2O_3$ can also play a part in this change ($2CaO + 2FeS + O = 2CaS + Fe_2O_3$ or $2CaO + MnO.Fe_2O_3 + O = CaO.Fe_2O_3 + CaO.MnO_2$). It is not, however, only the CaO split off from the $Ca_4P_2O_9$ which passes into insoluble compounds, but also the free lime that was there from the very beginning.

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* *Zeitschrift für angewandte Chemie*, 1892, p. 13.

Of the other constituents occurring in basic slag, mention shall be made in connection with the oxide slags. In the meantime it will be enough to point out that the calculation of the composition of basic slag is made by first calculating the tetra calcium phosphate from the percentage of phosphoric acid present, and then calculating the remainder as a silicate or oxide slag.

EXAMPLES.

A.—*Basic Open-Hearth Slag.*

	Per Cent.			Per Cent.
SiO_2	13·90	containing	oxygen	$=4·17=s$
P_2O_5	2·30	„	„	1·30
Al_2O_3	2·80	„	„	1·31
FeO	24·62	„	„	5·47
MnO	10·41	„	„	2·34
CaO	39·50	„	„	11·27
MgO	5·76	„	„	2·30

The 1·30 oxygen of the phosphoric acid corresponds to $1·30 \times 0·80 = 1·04$ oxygen in the lime (which gives $\frac{1·04}{4} = 0·26$ molecule of $Ca_4P_2O_9$). We have thus, after deduction of the oxygen in the calcium phosphate—

	Per Cent.	
Oxygen in SiO_2	$7·41=s$	
„ Al_2O_3	1·31	$21·65=b$
„ FeO	5·47	
„ MnO	2·34	
„ CaO	10·23	
„ MgO	2·30	

$$\frac{s}{b}=0·34$$

$$\frac{MgO+MnO+FeO}{CaO}=0·99$$

If one calculates all the Al_2O_3 as spinell, one finds the composition of the slag to be—

0·26 molecule calcium phosphate ($Ca_4P_2O_9$).
3·71 molecules olivine (R_2SiO_4).
0·44 molecule spinell ($RO.R_2O_3$).
12·48 molecules of free RO bases.

B.—*Basic Open-Hearth Slag.*

			Per Cent.
SiO_2	13·97	containing oxygen	=7·44
P_2O_5	1·83	,, ,,	1·03
Al_2O_3	5·17	,, ,,	2·43
FeO	20·61	,, ,,	4·58
MnO	12·12	,, ,,	2·73
CaO	40·26	,, ,,	11·50
MgO	6·44	,, ,,	2·58

The 1·03 oxygen in P_2O_5 corresponds with 0·82 lime-oxygen ($=0{\cdot}21Ca_4P_2O_9$), and there remains—

		Per Cent.	
Oxygen in	SiO_2	7·46=*s*	
,,	Al_2O_3	2·43	26·86=*b*
,,	FeO	4·58	
,,	MnO	2·73	
,,	CaO	10·68	
,,	MgO	6·44	

$$\frac{s}{b}=0{\cdot}27$$

$$\frac{MgO+MnO+FeO}{CaO}=1{\cdot}29$$

The slag consequently contains, with similar assumptions as before—

0·21 molecule calcium phosphates.
3·72 molecules olivine.
0·81 molecule spinell.
16·18 molecules free RO bases.

C.—*Basic Open-Hearth Slag Low in Phosphoric Acid.*

	Per Cent.		Per Cent.
SiO_2	23·77	containing oxygen	=12·66
P_2O_5	0·379	,, ,,	0·213
Al_2O_3	1·34	,, ,,	0·63
Fe_2O_3	2·59	,, ,,	0·77
FeO	14·24	,, ,,	3·16
MnO	29·06	,, ,,	6·46
CaO	11·22	,, ,,	3·21
MgO	16·90	,, ,,	6·76
S	0·175 (assumed to be combined with Ca)		

To the 0·213 of oxygen in phosphoric acid 0·16 lime-oxygen corresponds. There consequently remains—

		Per Cent.	
Oxygen in SiO_2		12·66 = *s*	
„	Al_2O_3	0·63	*b* = 20·83
„	Fe_2O_3	0·77	
„	FeO	3·16	
„	MnO	6·46	
„	CaO	3·05	
„	MgO	6·76	

$$\frac{s}{b}=0{\cdot}61$$

$$\frac{MgO+MnO+FeO}{CaO}=5{\cdot}37$$

The slag consequently consists of—

0·04 molecule calcium phosphate.
6·33 molecules olivine.
0·47 molecule spinell and magnetite.
5·29 molecules free RO bases.

D.—*Basic Bessemer Slag.*

	Per Cent.		Per Cent.
SiO_2	11·71	containing oxygen =	6·24
P_2O_5	18·15	„ „	10·23
Al_2O_3	1·01	„ „	0·47
Fe_2O_3	2·78	„ „	0·83
FeO	7·19	„ „	1·60
MnO	4·05	„ „	0·91 − 0·05 = 0·86
CaO	48·19	„ „	13·77
MgO	6·38	„ „	2·50
S	8·09	corresponding to oxygen =	0·05

8·15 lime-oxygen corresponds to the 10·23 P_2O_5 oxygen (2·05 $Ca_2P_2O_9$), and there consequently remains—

		Per Cent.	
Oxygen in SiO_2		6·24 = *s*.	
„	Al_2O_3	0·47	11·85 = *b*
„	Fe_2O_3	0·83	
„	FeO	1·60	
„	MnO	0·86	
„	CaO	5·59	
	MgO	2·50	

$$\frac{s}{b}=0{\cdot}53$$

$$\frac{MgO+MnO+FeO}{CaO}=0{\cdot}89$$

The mineralogical slag composition is consequently—

2·05 molecules calcium phosphate.
3·12 molecules olivine.
0·43 molecule spinell and magnetite.
3·87 free RO bases.

N.B.—The calculation of spinell and magnetite from the total of Al_2O_3 and Fe_2O_3 is, strictly speaking, not accurate, but can at least be looked upon as an approximation.

In finery slags free from lime, such, for instance, as that from the puddling-furnace, the ratio is somewhat different. The quantity of the lime is inadequate to bind the whole of the phosphoric acid present. The greater part of this acid must consequently be combined with other bases. Certain observations point to MnO as being the more important of these. Thus the analysis of a slag from a puddling-furnace which was obtained from three different furnaces in which the same materials were used showed—

	I.	II.	III.
	Per Cent.	Per Cent.	Per Cent.
SiO_2	16·75	14·08	14·89
Fe_2O_3	16·00	28·61	17·79
FeO	33·84	30·93	50·36
MnO	26·29	20·59	13·18
CaO	1·34	1·27	0·92
MgO	0·57	0·49	0·49
P_2O_5	4·65	3·60	1·90
MnS	0·76	0·52	0·57

Calculating the ratio $\frac{MnO}{P_2O_5}$, one obtains in the three cases—

5·56 per cent. 5·69 per cent. 6·90 per cent.

The phosphoric acid contents is consequently approximately proportional to the contents of MnO. This becomes still more evident if one considers the CaO as well as the MnO. One obtains, then, for the oxygen in—

	I.		II.		III.	
	Per Cent.		Per Cent.		Per Cent.	
MnO	5·93	} 6·31	4·64	} 5·00	2·97	} 3·23
CaO	0·38		0·36		0·26	
P_2O_5	2·62		2·03		1·07	

and the oxygen ratio in—

$\frac{MnO+CaO}{P_2O_5}$	2·41	2·46	3·01

If the MnO is not adequate to combine with all the P_2O_5, FeO probably takes a part.

While it has with certainty been shown that in phosphate slags only the calcium phosphate $Ca_4P_2O_9$ occurs, views vary as to the FeO and MnO phosphate present. Some believe that these are 3-basic,* and consequently correspond to the formula $Mn_3P_2O_8$ and $Fe_3P_2O_8$, while others here too consider that the tetra-basic phosphates † $Mn_4P_2O_9$ and $Fe_4P_2O_9$ occur.

Fortunately this affects the slag calculation but little. One finds in the first place the quantity of base oxygen corresponding to the P_2O_5 oxygen by multiplying the latter by the factor 0·6, while in the second case one must take the factor 0·8. The number of molecules of phosphate remains in this unchanged, and there is only a slightly increased quantity of residual basic oxygen for the silicate in the first instance. An example will make this clear, and for this we will select the first of the analyses of puddling-furnace slags given above:—

	Per Cent.
Oxygen in SiO_2	8·92
„ Fe_2O_3	4·80
„ FeO	7·52
„ MnO	5·93
„ CaO	0·38
„ MgO	0·23
„ P_2O_5	2·62

The 0·38 of lime-oxygen is corresponded to by 0·48 P_2O_5 oxygen. There consequently remains to combine with RO bases $2·62 - 0·48 = 2·14$ of P_2O_5 oxygen. If we in the first place assume that here too tetra- or octo-basic phosphates are formed, the 2·14 of P_2O_5 oxygen corresponds to 1·71 of RO oxygen, and there remains—

	Per Cent.	
Oxygen in SiO_2	$8·92 = s$	
„ Fe_2O_3	4·80	$16·77 = b$
„ FeO	7·52	
„ MnO	4·22	
„ MgO	0·23	

$$\frac{s}{b} = 0·53$$

---

* Or rather 6-basic.

† Or more accurately 8-basic.

Slag Constitution.

0·10 molecule calcium phosphate ($Ca_4P_2O_9$).
0·43 molecule manganese phosphate ($Mn_4P_2O_9$).
4·46 molecules olivine.
1·60 molecules magnetite.
1·45 molecule free RO bases.

If, on the other hand, one assume the existence of a tribasic manganese phosphate, 1·28 RO oxygen will correspond to 2·14 P_2O_5 oxygen, and there remains—

	Per Cent.	
Oxygen in SiO_2	8·92 = s	
„ Fe_2O_3	4·80	17·20 = b
„ FeO	7·52	
„ MnO	4·65	
„ MgO	0·23	

$$\frac{s}{b} = 0·52$$

Slag Constitution.

0·10 molecule calcium phosphate ($Ca_4P_2O_9$).
0·43 molecule manganese phosphate ($Mn_3P_2O_8$).
4·46 molecules olivine.
1·60 molecules magnetite.
1·88 molecules free RO bases.

III.—OXIDE SLAGS.

Very little is known as to the actual constitution of oxide slags. It is certain that the sesquioxide bases can enter into combination with the monoxide bases; but while most suggest for these the formula $RO.R_2O_3$, Stead* and Ridsdale consider the following compounds to exist:—$(CaO).Al_2O_3$; $(CaO)_3.Fe_2O_3$; and $(CaO)_3.Fe_3O_4$. The latter found in basic Bessemer slag, as has already been mentioned, two constituents of the following composition:—

a. Black magnetic needles containing 10 per cent. $CaO.Al_2O_3$ + 45 per cent $(CaO)_3.Fe_3O_4$ + 33·5 per cent. $(CaO)_3.Fe_2O_3$.

β. Non-magnetic black crystals with 15 per cent. $CaO.Al_2O_3$ + 73 per cent. $(CaO)_3.Fe_2O_3$.

The theoretical possibility of compounds $RO.R_2O_3$, as well as of $(RO)_3.R_2O_3$, cannot be disputed, as can be represented by the following constitution formulæ:—

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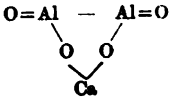
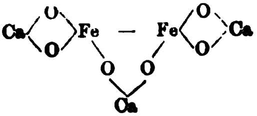
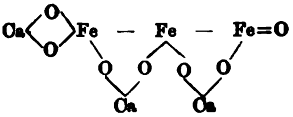
* ***Stahl und Eisen***, **1887, p. 557.**





For the assumed compound $(CaO)_3Fe_3O_4$ the following formula would apply:—



It is, however, just as possible that, as a matter of fact, corresponding to spinell, only the compound $RO.R_2O_3$ exists, which, however, may crystallise with excess quantities of RO and R_2O_3. To the latter assumption support is given by the occurrence in nature of the magnetic iron ores, &c., in which, as compared with the formula $RO.R_2O_3$, both monoxide bases and sesquioxide occur in excess.

To be able to form any definite judgment on this point detailed investigations are necessary, especially of the fusion curves of such slags. In the meantime it will suffice for practical purposes to consider these slags as mixtures (or solutions) of $RO.R_2O_3$ and RO (or respectively R_2O_3.)

It need not be pointed out that in these slags, in addition to the above-named compounds, small quantities of phosphates, silicates, and sulphides may also occur.

A special class of oxide slags occurs in iron alloys under certain conditions in the form of inclusions. Their characteristic is the deficiency of sesqui-oxides (accidentally admixed alumina being disregarded). This is owing to the fact that they are at once reduced to monoxides by the excess of metal near them. These inclusions consist of mixtures of monoxides with silicates and mono-sulphides. Occasionally, however, the silicates are quite subordinate. The inclusions may, of course, also contain phosphates. Examples of the composition of such inclusions are afforded by the following analytical results:—

	I.	II.	III.	IV.	V.
SiO_2	6·01	8·33	10·00	21·44	27·81
P_2O_5	...	...	...	0·54	0·84
Al_2O_3	0·49	...	trace	0·83	0 28
FeO	29·27	...	22·60	24·25	17·19
MnO	59·65	59·61	67·36	24·73	24·71
CaO	0·91	...	...	17·24	14·41
MgO	0·33	...	...	9·58	19·21
Mn	2·16	...	3·10	1·02	0·24
S	1·26	...			0·14
Totals	100·08	...	103·56	99·63	104·83

The exceedingly minute portions of material available for analysis is the reason for the fact that the totals in some cases considerably exceed 100.

The proportion of oxygen in the above slags is shown in the following table:—

Oxygen in	I.	II.	III.	IV.	V.
SiO_2	3·20	4·44	5·33	11·42	14·81
P_2O_5	—	...	...	0·30	0·47
Al_2O_3	0·21	...	trace	0·39	0·13
FeO	6·50	...	5·02	5·39	3·82
MnO	13·44	13·43	15·18	5·57	5·56
CaO	0·26	...	...	4·93	4·12
MgO	0·13	...	...	3·83	7·68
CaO in phosphates	...	...	...	0·24	0·38
Equivalent to S	0·63	...	0·56	0·19	0·07
Disposable base O	20·54	...	20·20	19·87	20·93
Oxygen ration of the silicates	0·15	...	0·26	0·57	0·71

From this, the composition of the slag is calculated to be as follows:—

Molecules.	I.	II.	III.	IV.	V.
Olivine	3·20	4·44	5·33	11·42	14·81
Calcium phosphate	...	?	...	0·06	0·10
Manganese sulphide	0·63	?	0·56	0·19	0·07
Free RO bases	17·34	?	14·97	8·45	6·12

The following slag from soaking pits:—

	Per Cent.			Per Cent.
SiO_2	3·14	containing	of oxygen	1·67
P_2O_5	0·068	,,	,,	0·039
Fe_3O_4	24·77	,,	,,	6·83
FeO	68·31	,,	,,	15·18
MnO	1·047	,,	,,	0·232
CaO	1·03	,,	,,	0·294
MgO	0·83	,,	,,	0·332
S	0·021	,,	,,	0·0105
Total	99·216			

The degree of silicification—

$$=\frac{1·67}{22·73}=0·07$$

From this the mineralogical composition of the slag is calculated to be—

	Molecules.
Manganese sulphide	0·011
Calcium phosphate	0·008
Gehlenite $(RO)_3\ (SiO_2)_2$	0·84
Magnetite	1·71
Free RO bases	13·48

As an addendum, attention must be drawn here to the connection which exists between slags and fire-resisting materials. The former are relatively easily fusible solutions in one another of several substances, themselves only fusible with considerable difficulty. Fire-resisting materials can be considered as the more difficultly fusible members of the slag series. This purely theoretical relation between slags and refractory materials has, however, some importance in practice. Thus, the rule is derivable from this, that only such refractory materials should be used for furnace construction as are insoluble, or only very slightly so, in the slags that will be produced in any particular smelting process.

IRON AND STEEL FROM THE POINT OF VIEW OF THE "PHASE-DOCTRINE."

By Professor H. W. BAKHUIS-ROOZEBOOM, Ph.D. (Amsterdam).

It is a great honour for me to present to the Iron and Steel Institute a summary of a recent article of mine under the above title,* at the request of your President, Sir W. C. Roberts-Austen, whose eminent researches form, in fact, the basis for my theoretical study.

My guide in this study is the phase-doctrine of Gibbs. I think as yet this is very little known by most of the members of this Institute, but it is, nevertheless, a conception which has already proved its usefulness in the explanation of many an entangled chemical problem. One of the chief objects of this inquiry is to find out the conditions of the existence of the phases of a system of one or more components. In applying it to iron and steel, we have a system of two components—iron and carbon; and by the phases of this system we understand all the distinct forms which may appear in the system. We have, therefore, to consider the following phases: carbon, iron, which, if we accept the allotropic theory, may present itself in three phases—γ, β, and α; liquid solution, solid solution of carbon in γ iron or martensite; cementite or carbide, Fe_3C. Thus it will be evident that a "phase" may be liquid or solid, may be an element or a compound, or a homogeneous mixture of variable concentration. But "pearlite" does not represent such a phase, for it is a conglomerate of two solid phases, ferrite or α iron and cementite.

Now it has been deduced from thermo-dynamical principles that there are only a very limited number of ways in which a liquid phase formed by two components may solidify to one or more solid phases; and this being so, there are a limited number of ways in which a transformation in or between these solid phases may take place. Furthermore, the application of the phase-doctrine is so general, that it matters not whether we start from a liquid phase built up from water and a salt, or from two salts fused together, or from two silicates, or from two metals, or from iron and carbon. Therefore the point of view of the phase-doctrine embraces widely different problems.

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* *Zeitschrift für Physikalische Chemie*, 1900, vol. xxxiv. p. 437.

I have, therefore, examined the problem of iron and steel from this point of view, making use of the most accurate numbers obtained by Sir W. Roberts-Austen in his recent studies. Fig. 2 (Plate XX.) represents the results of my study. It resembles in many respects Fig. 1, which is Roberts-Austen's. In fact, the new lines that are introduced principally result from the knowledge I had obtained as to the solidification and transformation of solid solutions, which enabled me to give a better correlation of the different parts of the figure.

Let us consider first the solidification of liquid solutions with 0–2 per cent. carbon. I have added the curve A *p r a*, which has been traced as a straight line, because its position is not exactly known. All these solutions with 0–2 per cent. of carbon solidify to homogeneous solid solutions, but the process takes place in the following manner.

Take a solution *q*, trace the horizontal line *q p*, then *p* represents the composition of the first crystals that separate from that solution. They *must* contain less carbon than the liquid. The liquid will be enriched in carbon, and its temperature of solidification is thereby lowered, and so the liquid passes successively from *q* to *s*. In the meanwhile the mixed crystals of iron and carbon change also with the fall of the temperature from *p* to *r*, and at last the whole solution becomes solidified into homogeneous mixed crystals of the composition *r*, that of the original liquid being *q*. The solidification, however, has not taken place at a constant temperature, but over the interval *qr*.

So it proceeds until the point *a* is reached, which indicates the presence of 2 per cent. of carbon. From 2–4·3 per cent. of carbon there is first a gradual solidification as before, until the remaining liquid has reached the point B, and the crystals have reached the point *a*, and then the remaining liquid solidifies at a constant temperature of 1130° according to Roberts-Austen, so as to form what I like to call a conglomerate of carbon and mixed crystals of the composition *a*, which may perhaps be 2 per cent. of carbon.

At 1130° there exists by contact with one another a liquid solution of 4·3 per cent. of carbon, solid carbon (graphite), and a solid solution (martensite) containing 2 per cent. of carbon. Three phases are the maximum that may coexist, according to the phase-doctrine, in the case of stable equilibrium at one temperature and a constant pressure.

Turning to the field above the curve AB, all its points represent liquid solutions at various temperatures and concentrations; therefore it may be called the field of the liquid phase. In the same way the points beneath Aa will represent different solid solutions, each of which may exist undisturbed by the fall of temperature so long as a vertical line denoting their composition does not encounter a new curve.

In the case of the field AaB it is, however, otherwise. A point in the field does *not* represent a homogeneous phase, but a complex of two phases. Take a point on the line pq; then at this temperature we have seen that there can exist in contact with each other the liquid phase q and the solid solution p; a liquid with less carbon than q, and a solid with more carbon than p are both impossible at the given temperature; therefore, a point between p and q can only represent a complex of a certain proportion of the liquid phase q and another of the solid p. The nearer the point to p, the greater is the proportion of the solid solution—and conversely. What condition will be attained at a given temperature will depend on the concentration of the initial liquid before solidification began.

It will be the same in the other fields, in which the names of two phases are inscribed in Fig. 2. Their points always represent a complex of two phases which are to be found at the ends of a horizontal line drawn through the field. So the point n represents a conglomerate of martensite of the composition m and cementite o, the whole perpendicular LF indicating cementite, which is a compound of definite composition at all temperatures.

Liquid solutions with more than 4·3 per cent. of carbon deposit graphite as long as they traverse the field from BD to BC.* The remaining liquid descends from D to B and solidifies totally at 1130° to martensite and graphite.

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* Two questions arise here: 1st. Whether the graphite which is separated is pure carbon, or whether it is also a solid solution (of iron in carbon)? 2nd. Whether the graphite that separates retains the same form until its fusing point?

We will now first trace the history of the mixed crystals which can exist beneath the curve A*a*. I have changed nothing in the Roberts-Austen lines GO, OS, and SE, and the interpretation of the separation of β iron, α iron, or cementite is also accepted. That a solid solution may reject one of its components or a compound just as a liquid solution does when it is cooled, was an entirely unknown phenomenon a few years ago, but it has now been demonstrated in some cases which have been the object of researches by my pupils.

The existence of three allotropic states of the iron, the discovery of which we owe to Mr. Osmond, is not exceptional. The researches of later years have so multiplied our knowledge of the allotropic forms of solid bodies, that it is at present far more peculiar for a body not to present allotropy than to do so. As regards metals, there is the new case of tin, which presents a transition point at 20° C., just like the transition point of γ into β iron at 890°. The succession of three such states in iron is no longer to be wondered at, for ammonium nitrate shows four of them, and therefore the transformations of the martensite crystals with 0–0·86 per cent. of carbon only admits of a rational explanation if the existence of the three varieties of iron are admitted. The right understanding of these phenomena was, however, impeded by the fact that no analogous phenomena were known to occur at more convenient temperatures. I have, therefore, pointed out the complete analogy of the lines GO and OS with the lines that represent the successive separation of the different modifications of ammonium nitrate from its liquid solution, according to the amount of water present. The same phenomena are observed in the separation of solid $TlNO_3$ or $AgNO_3$ from their fused mixture.

My studies on mixed crystals led me, however, to consider also the possibility that the β and α iron also hold some carbon in solid solution, although less than the γ iron. This would give some complications in the figure G O S P which it is difficult to describe briefly. It would, however, greatly influence the results obtained in an attempt to deduce the molecular weight of the carbon in the solid solution from the observed lowering of the transition point.

As regards the iron-carbon alloys with more than 2 per cent.

of carbon, my results are more at variance with those of Sir W. Roberts-Austen. Beneath the line *a* B C at 1130° in the normal case there should be nothing but a solid conglomerate of two phases, viz., graphite and martensite with 2 per cent. of carbon. Firstly, I have traced the line *a*E to indicate that the amount of carbon in the martensite falls simultaneously with the temperature, and this would induce a further separation of graphite. Then at about 1000° the line *a*E meets the cementite line SE of Roberts-Austen. This can have no other meaning than that at 1000° there is in the normal state of stable equilibrium an abrupt transformation of the graphite into carbide (cementite), according to the equation—

Martensite 1·8 per cent. C. + Graphite = Cementite (Fe_3C).

I have sought for analogies to illustrate this peculiar transformation. There are as yet only two remote analogies, both of which were discovered in my laboratory—the transformation of a solid solution of *d* and *l* camphor-oxime in the racemic compound, and the transformation of a solid solution of HgI_2 and AgI_2 into the compound HgI_2, $2AgI$. They are the very first examples in which a transformation from a solid solution into a compound has been studied. Both have, however, the peculiarity that at higher temperatures the series of mixed crystals that can exist, embraces also the ratio in which the components form the compound. There is, on the contrary, no solid solution possible above 1000° with a percentage of carbon equal to that in Fe_3C. Therefore we have here a type of the second method of formation of compounds such as presents itself very often in liquid salt solutions; for instance—

Salt solution + anhydrous salt = hydrate of salt.

The formation of iron carbide from martensite and graphite is doubtless the analogous formation of a compound from a solid solution. But then the temperature of 1000° is a transition point; that is, only at that temperature can the three phases coexist, and therefore the transformation of all the conglomerates of martensite and graphite must take place at this temperature; the border line EFH must be horizontal.

It is impossible to state briefly here all the arguments which have led me to accept this line in preference to the lines EK and KL of Roberts-Austen and of Stansfield; nor can I sum up the considerations which I have adduced to explain the many anomalous results obtained with highly carburised iron. A prominent part is played by the retardations which are possible in all the processes of transformation which occur during cooling. There is also to be taken into account the influence which retardation has upon the production of cementite during the period of solidification, and during the two following periods above and below 1000°.

Again, the straight line PSK at 690° is also wholly in harmony with the known interpretation that it gives the transformation of the residual solid solutions of 0·85 per cent. of carbon (point S) into a conglomerate of α ferrite and cementite, which is known by the name of pearlite. To the right of S this same transformation is accomplished at the same temperature in martensite which is accompanied by cementite; to the left of S it is accomplished in martensite accompanied by α ferrite. Therefore 690° is analogous to a eutectic point.

As to the possibility of passing this point as well as the curves GO, OS, ES, in abrupt cooling, and thereby preserving to the ordinary temperature the γ state of the iron as mixed crystals or solid solutions, I have nothing to add to this way of explaining the process of hardening.

The different fields obtained in Fig. 2 give the limits of concentration and temperature for the most prominent of the phases that appear in the carbon-iron system. There are some others about which our knowledge is far too imperfect to make it possible to indicate their place. Only in the case of austenite has such an attempt been made, but the position austenite should occupy in the system still remains highly hypothetical.

The previous endeavours to determine the molecular weight of carbon in the solid solution may be re-examined in connection with the new line A*a*, and possible alterations in the figure GOM. The results of such an examination point to the fact that the carbon molecule probably only contains a single atom, but it cannot be decided whether the carbon is free or is present as Fe_3C.

THE PRESENT POSITION OF THE SOLUTION THEORY OF CARBURISED IRON.

PART II.

BY A. STANSFIELD, D.Sc., Assoc. R.S.M.

Introduction.

IN my paper at the Autumn meeting in 1899, an outline only of the solution theory of carburised iron, in which our President is so much interested, was presented to the Institution, and no attempt was made to reconcile with this theory the conflicting opinions and statements which have been made from time to time. In the present paper, which may be regarded as a continuation of the first, I propose to review as far as possible all the experimental evidence that appears to bear upon the subject, and also to incorporate the results of some fresh experiments of my own.

In view, however, of the magnitude of such a task, I shall limit the present paper to a consideration of a part only of the whole subject; the part selected being the conditions under which graphite and cementite are formed in carburised iron.

The great interest of the relations existing between carbon and iron has attracted the attention of no less an authority than Professor Bakhuis-Roozeboom, whose knowledge of the analogous cases of fused mixtures of salts and of saline solutions generally, gives great value to the paper he has just written: "Eisen und Stahl vom Standpunkte der Phasenlehre."* No apology will therefore be needed if, in treating the subject, I attempt to meet some of the questions which he considers demand immediate attention, and in doing so I can refer to those of his diagrams which will be reproduced in the summary which he is communicating to the Institute.

In discussing the formation of graphite and cementite, it will be advisable to begin with the molten material, and to trace the changes which occur as it cools.

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* *Zeitschrift für Physikalische Chemie*, vol. xxxiv. 1900, p. 437.

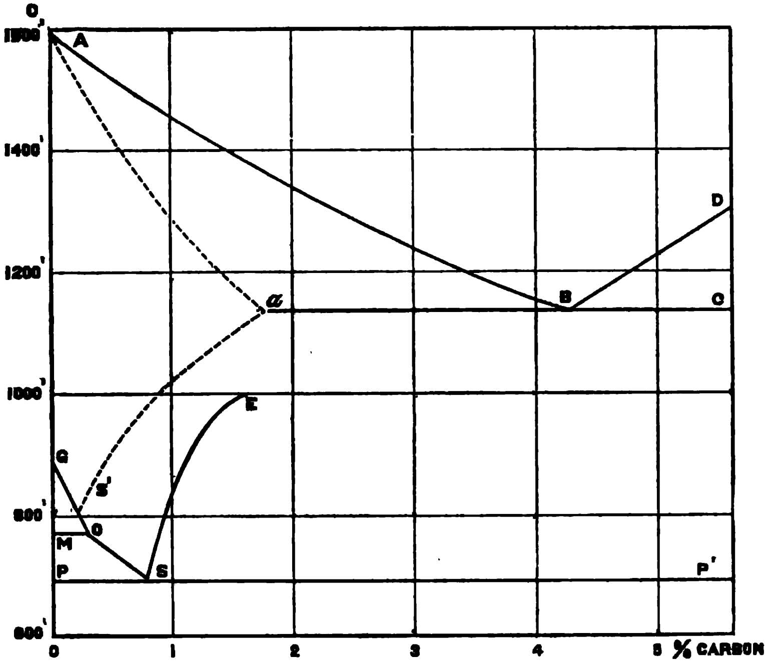
The Solidification of Carburised Iron.

This, as was stated in the first paper, is now generally admitted to be closely analogous to the freezing of a saline solution, the solids which separate being:—(1) Iron (in the γ state), containing a variable amount of carbon dissolved in it; (2) graphite; and (3) a eutectic or fusible mechanical mixture of 1 and 2.

The amount of carbon which is held in the state of solid solution in the iron depends upon the amount of carbon in the fluid solution from which it separated, and, until the saturation point is reached, it is probably roughly proportional to it. Professor Roozeboom has recognised this fact by the addition, in Fig. 2 of his paper, of the line A*a*, which represents the proportion of dissolved carbon in the solid iron which separates at any temperature, and this line, and other analogous lines which will be found in his paper, enable the very complicated facts to be more readily interpreted.

The line A*a* is drawn from A, the freezing-point of pure iron, to a point *a* on the eutectic line *a*BC; the position of *a* denoting the maximum amount of carbon which solid iron can permanently hold at that temperature without separation of graphite. The exact position of *a* has not yet been determined, but it could probably be obtained experimentally by cooling a series of pure carburised irons very slowly from the molten condition to just below 1130° and then quickly to the ordinary temperature: the proportion of carbon for which graphite just began to separate, would indicate the true position of *a*.

In my last paper I placed *a* at 1·2 per cent. carbon, as this was the point at which the formation of graphite was evident in the cooling curves. A careful consideration of the progress of solidification as described by Professor Roozeboom in his summary, will bring to light the important fact that the process can only take place as he describes it *if the rate of cooling is very slow.* Thus in his Fig. 2, tracing the solidification of a liquid having the composition *q*, the solid which separates will have at first the composition *p*, but as the composition (and temperature) of the residual liquid changes from *q* to *s*, that of the deposited solid will have changed from *p* to *r*. Now we know that when solid crystals are formed in a solution, it is the solution in *immediate contact* with the crystals which is at first impoverished, but, owing to the rapid mixing and diffusion which takes place in liquids, each part of the solution is kept at approximately the same degree of concentration as the rest. In the case of solids, however, it is obvious that no mechanical mixing can take place, and the rate of diffusion in solids has been shown to be much less than in liquids, and this must obviously be the case. It will be evident, therefore, that if in the solution *q* a crystal of steel (that is, iron with carbon dissolved in it) is formed having the composition *p*, and if subsequent growths of the crystal have compositions varying from *p* to *r*, we have by the time the residual liquid has reached the composition *s*, not a uniform crystal of composition *r*, but a crystal of composition *p* at the centre and *r* at the



Equilibrium Curve for Carburised Iron.

outside. The *average* composition of the crystal will be between p and r, and there will, therefore, be some of the enriched liquids remaining, which may eventually form a eutectic. It will be evident, therefore, from this that the process of solidification will not in general stop at the line Aa, but that the formation of the eutectic alloy, with subsequent separation of graphite, will take place in steels containing a smaller percentage of carbon than corresponds to the point a (which is about 1½ per cent. or 2 per cent.). In proportion as the rate of cooling is decreased, the diffusion of carbon in the solid steel crystals will make the whole approximate more and more to the composition r, and when equilibrium has been established, it will coincide with r, and the whole liquid will consequently have solidified, a fact which is capable of easy arithmetical demonstration. In a true equilibrium curve, which Professor Roozeboom's Fig. 2 really is, the eutectic line Ba will stop where it meets the line Aa.

In view of the above, it is probable that the position of a will be somewhat to the right of that given in my last paper,* which was 1·2 per cent. carbon. The position assigned to it by Professor Roozeboom (2 per cent.) is probably approximately correct. In my last paper I advanced the hypothesis, based on the slope of the line AB, that the carbon in fluid iron was monatomic, and that the iron which solidified contained about half as much carbon as the liquid from which it was formed. This would give to a the composition 2·1 per cent. carbon, which is in general agreement with the 2 per cent. suggested by Professor Roozeboom. The monatomic condition of carbon in molten iron is, moreover, supported by the observation of Ramsay that the metals in fluid alloys are monatomic, carbon here playing the part of a metal.

The following equation, which is a modification of that of Le Chatelier, enables the exact shape of the line Aa to be deduced from that of the line AB, provided that the latent heat of fusion of pure iron be known. The assumption is also made that the carbon is monatomic in the liquid metal. In a somewhat abbreviated form, which will be sufficiently accurate for the present purpose, the equation is $2\frac{dx}{x}(1-c) = \frac{\lambda}{T^2}dT$. In this equation x is the number of molecules of iron in 100 molecules of iron

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* *Journal of the Iron and Steel Institute*, 1899, No. II. p. 174.

PLATE XX.

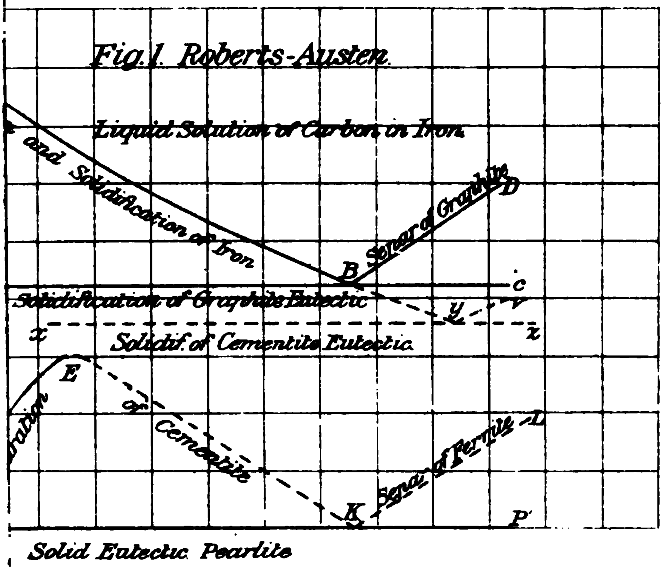
Fig. 1. Roberts-Austen.
Liquid Solution of Carbon in Iron.
and Solidification of Iron
Separ. of Graphite
D
B
c
Solidification of Graphite Eutectic
y
v
x
z
Solidif. of Cementite Eutectic.
E
ration
of Cementite
Separ. of Ferrite
D
K
P'
Solid Eutectic Pearlite

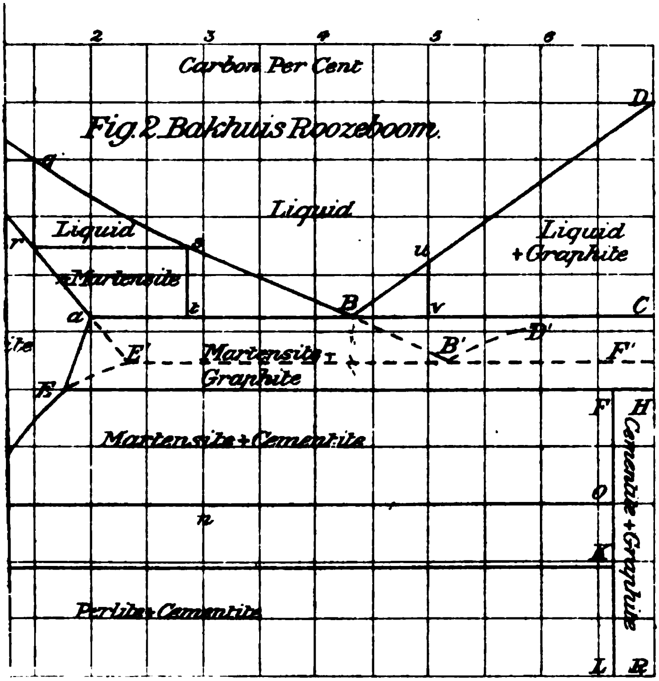
Fig. 2. Bakhuis Roozeboom.

Figs. 1 and 2.

Ballantyne, Hanson & Co. Edinburgh & London.

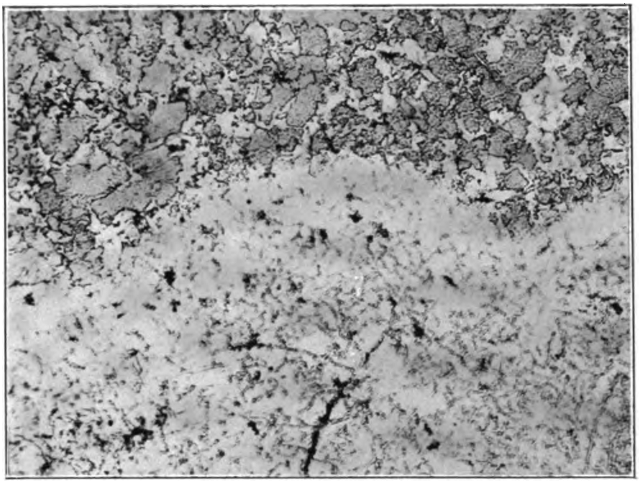

Fig. 1.—Pure carburised iron annealed for two days. Portion near edge × 56 D.

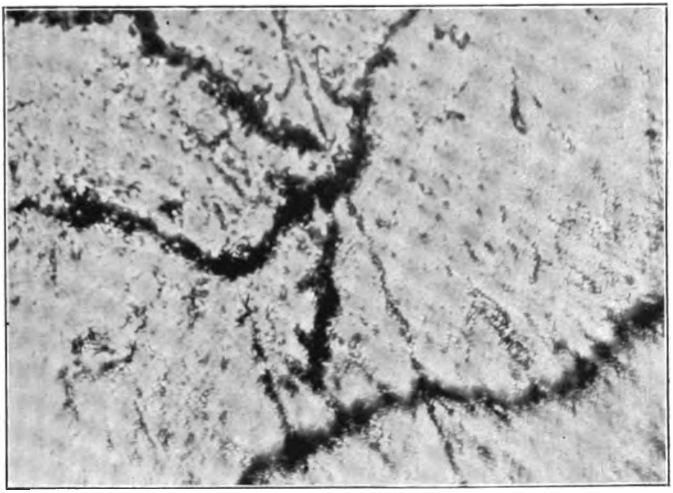

Fig. 2.—Lower portion of Fig. 1 × 1580 D.

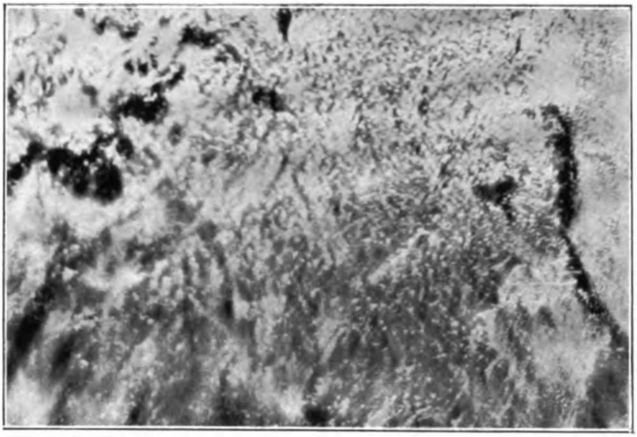

FIG. 3.—Upper portion of Fig. 1 × 1580 D.

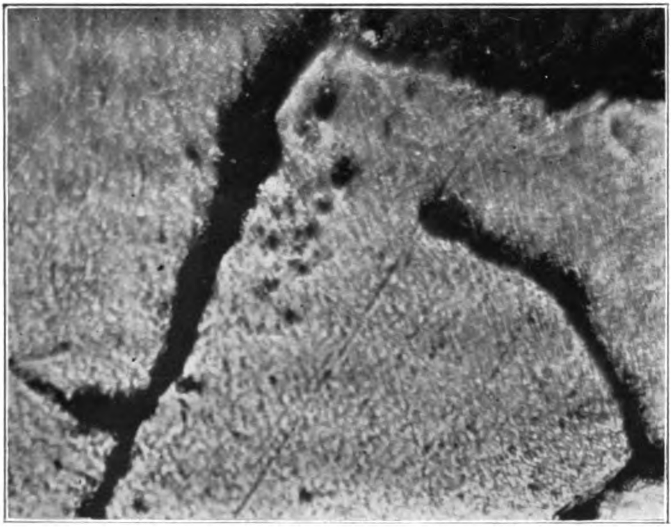

FIG. 4.—More highly carburised iron, containing when fluid 7 per cent. carbon and 3 per cent. silicon. Combined carbon 0·22 per cent. The section shows only ferrite and graphite.

and of carbon in the molten alloy. T is the temperature of solidification measured from the absolute zero ($-273°$ C.), and c is the ratio between the percentage of carbon in the solid and in the liquid from which it was formed, the percentage being reckoned in molecules. λ is the latent heat of fusion of one gram molecule of iron. Taking Person's value of 20 calories per gram, it becomes 1120.*

The result of this calculation places a at about 2 per cent., but I have adopted 1·8 per cent. provisionally, as it appears to agree better with the evidence obtained from other sources. The general curvature of the line Aa is, however, obtained by means of the calculation; it will be observed that it has a somewhat stronger curvature than the line AB.

Turning now to the solidification of liquids to the right of B, the process is the same as has already been described, except that a eutectic alloy is finally left containing about 4·3 per cent. of carbon. This solidifies at points on the line aB forming a mechanical mixture of graphite and of a solid solution of carbon in iron having the composition a. I may incidentally observe that the true meaning of a eutectic alloy has already been fully described and need not be dealt with here.

Passing to the right of B, an excess of carbon is found above the amount required to make the eutectic, which contains 4·3 per cent. of carbon. This excess of carbon crystallises out as graphite at points on the line BD. Professor Roozeboom asks whether this graphite is pure carbon, or whether it too is a solid solution of iron in carbon. In order to test this I intend to determine the amount of iron in a quantity of "kish" which separated from a rich sample of carburised iron during slow cooling from the molten state. The kish had previously been boiled with dilute hydrochloric acid to extract any iron that might be mechanically entangled.

There will still, however, be some uncertainty whether the iron was really dissolved or only mechanically mixed with the graphite. The question is not of great importance, but if a series of determinations of the amount of iron in graphite were found to give concordant results it would appear to be in favour of Professor Roozeboom's suggestion.

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* Roberts-Austen and Stansfield, *Bull. Phys. Congress*, Paris, 1900.

With regard to the slope of the line BD, it must be remembered that this part of the curve is somewhat difficult to obtain by the ordinary method of taking cooling curves, as the heat evolved by the separation of graphite is very slight, and the extrusion of graphite from the cooling mass renders the carbon percentage of the original fluid metal somewhat uncertain. If the line BD is prolonged up to the point which would represent pure carbon, it will be found to reach a temperature of at least 8000° C. We do not know at what temperature graphite melts, as Moissan has shown that it volatilises without any sign of fusion at the highest temperature of the arc, say about 3000° C., but its melting-point can scarcely be so high as 8000° C. This is, however, not at all anomalous, as it is in agreement with the fact that the ideal curve is not in general a straight line, but has one or two points of curvature which would probably reduce the melting-point of graphite to a more reasonable temperature.

Professor Roozeboom's question whether there is any change in the character of the separated solid as we proceed up the line BD, must, I think, be answered substantially in the negative, as the tendency would be for the solid to become more and more nearly pure carbon, and it is practically pure to begin with; we know, moreover, of no decided change in the physical nature of graphite until it reaches the temperature of the arc, at which it rapidly vapourises.

Changes after Solidification.

In the lower part of the equilibrium curve, relating to solidified cast iron, it will be seen that important alterations have been made since my previous paper. The difficulty in obtaining these curves, by the usual method of taking cooling curves, has arisen from the extreme slowness with which the changes occur in the solid metal, and it may be well to give a short account of the different stages by which our present knowledge of the subject has been gained. When the diagram was first published, in 1897,* the curve SE, which shows the solubility of cementite in pig iron, was left incomplete at E, as the positions of points beyond this were uncertain. The solution theory appeared to demand that the line should continue horizontally from E (as Professor Roozeboom has drawn it), but this would have indicated that the amount of cementite in cast iron should either remain constant or should increase, with further additions of carbon; and while we know that this does occur to a certain extent, as in the case of white pig, still further additions of carbon, especially when the iron is subjected to very slow cooling, are known to result in a marked reduction in the proportion of cementite, a fact which is not consistent with the line EF in Professor Roozeboom's Fig. 2 being horizontal, except under special conditions to be described later. Up to this point the evidence had appeared to support the hypothesis that cementite was a stable body at temperature below about 1050°, at which temperature experiments had shown that it dissociated into iron and graphite. Professor Roozeboom's curve shows that the hypothesis which had been tacitly accepted is not in accordance with experimental facts. He shows that the hypothesis necessitates the assumption that *all* the graphite which is liberated as the iron solidifies, should at 1050° combine to form cementite, and that if we consider more and more richly carburised iron this process should go on until at 6·6 per cent. of carbon the solidified mass, if cooled sufficiently slowly, would consist of nothing but cementite; while it is a matter of common experience that, under these conditions, there would be a large amount of graphite, and but little cementite. It follows from this that at the temperatures under consideration cementite is not really a stable body.

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* Roberts-Austen, Fourth Report to Alloys Research Committee. *Proc. Inst. Mech. Eng.*, 1897.

The fact that slowly cooled iron, when rich in carbon, contained very little carbon in the combined state has long been known in the case of pig irons, in which, however, the simultaneous presence of silicon somewhat complicates the problem. Perhaps the earliest experiment in which pure materials were used was one described by Dr. Percy,* in which he melted pure iron in crucibles brasqued with lamp-black, and obtained a cast iron containing a little more than 4 per cent. of graphite, and with no sensible amount of combined carbon. Later experiments, showing practically the same thing, can be found described in the Journal of this Institute, and some experiments of my own on the effect of prolonged annealing on carbonised iron, which in the main agree with those of Dr. Percy, will be described a little later, as they appear to raise fresh points for discussion.

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* Percy's "Metallurgy, Iron and Steel," 1864, p. 113.

The results of these experiments and of the well known behaviour of richly carbonised iron can only lead us to the belief that not only does the graphite *not* combine with the iron on slowly cooling to 1050°, but that the 2 per cent. of carbon which the solid iron at first contained is rejected as graphite and not as cementite, if the metal is cooled sufficiently slowly. In other words, we are confronted with the highly important fact that carbon is more soluble in iron when it is presented to it as cementite, than when it is presented as graphite. Several analogous cases are known among aqueous saline solutions, in which the dissolved salt can separate in two or more states; either anhydrous (corresponding to the graphitic state of carbon), or containing water of crystallisation (corresponding to Fe_3C). In some of these cases either form of the salt can be made to separate at will from the solution by placing in it a crystal of the desired variety, and this probably throws light upon the conditions under which graphite or cementite separates. Normally, graphite should separate, being less soluble than cementite, but, as was explained in my last paper, graphite is very bulky, and when it is remembered that the mass from which it separates is solid, it will be evident that its separation from the solid will be opposed by a very considerable force: cementite, therefore, and not graphite, is usually found in steel. If, however, flakes of graphite have separated on solidification, as in grey pig iron, these present many nuclei, around which more graphite can form, and thus relieve the mechanical pressure.

Professor Roozeboom in his paper takes the "Phase-Rule" of Gibbs as his guide, and it may be well to consider the subject from this point of view. The phase-rule lays down in effect that in a system such as that of the carburised irons, in which two distinct substances (carbon and iron) are involved, but in which certain forms or phases of carbon or iron, or carbon-iron solution, or carbon-iron compound, are present, no more than two of these phases can exist in equilibrium with each other except at a particular temperature.

In the case of a solution of salt in water, this would mean that you could only have salt and ice and solution together at a particular temperature (the eutectic temperature), and that at any other temperature you could only have ice and solution or salt and solution (at temperatures above the eutectic), or ice and salt (at temperatures below the eutectic). In the case of a salt solution this is quite evident, but the value of the phase-rule is that we can apply it with equal confidence to cases where we do not, to begin with, know the answer to our question.

Applying the rule to the case of solid carburised iron at temperatures above that of all the known allotropic changes—we have the four possible substances of iron, graphite, cementite, and solid solution of carbon (either graphite or cementite) in pig iron. The rule tells us that only two of these can in general exist permanently together.

If we have a solid solution of carbon in iron any excess of carbon must be *either* as cementite or as graphite; we cannot have both together. We do, of course, find all three substances in the same piece of metal, but we may feel assured that they are only there because they have not had sufficient time or opportunity for effecting the desired transformation. This alternate possibility can easily be observed practically by thoroughly analysing steel or cast iron of varying degrees of carburisation. There will be found to be either practically no graphite or practically no cementite. My own experiments show this very well, although the samples were only annealed for a couple of days (Fig. 1).

If then we must choose between graphite and cementite, which must we select, and why is it that sometimes one and sometimes the other appears? The answer is that graphite and not cementite is the stable form; this being shown by the experiment of annealing a cast iron containing originally both cementite and graphite.

The absence of graphite in most steel, even when annealed, arises from the fact that under the ordinary conditions (which probably include a considerable mechanical opposition to the formation of graphite), a solid solution of carbon in iron does not readily deposit graphite even when it is considerably supersaturated with respect to it, but that cementite will readily separate as soon as its saturation-point is reached. It will be remembered that in the case of the salt solution three phases (salt, ice, and solution) could exist together at one particular temperature. In Professor Roozeboom's Fig. 2, the analogous temperature at which cementite, graphite, and solution could exist together was represented by the point E, at which the solubility curve of cementite SE, met that of graphite *a*E. If, however, as I think we must admit, the solubility of graphite is less than that of cementite, throughout the range of temperature under consideration (900 to 1130), and in the absence of mechanical pressure, the curves cannot meet, and there can be no temperature at which graphite, cementite, and solid solution of carbon in iron can be in equilibrium. The curve of solubility of graphite in iron has been drawn provisionally as *a*S′, because it must pass through *a*, and the experiments alluded to above suggest that, at somewhat lower temperatures, it approaches closely to the line, AG, of pure iron. As regards the general shape of the curve it is drawn roughly in accordance with the equation of Le Chatelier, and I believe he has already suggested that the curve should occupy some such position. It will be evident from what has already been said that the position of this curve could not be detected by means of the ordinary cooling curves, but it is to be hoped that suitable experiments will be made to obtain its correct position and that of other parts of the diagram which are at present somewhat uncertain.

Equilibrium Curves.

When the evidence with regard to the fusibility of metallic alloys was first obtained by means of a series of cooling curves, the point or points of solidification of each alloy were plotted on a diagram which summarised the results of the whole series of cooling curves, and which was known as a freezing-point curve. The term was retained for a while in connection with the carbon-iron series, although many of the points there represented denoted changes occurring after solidification. A more comprehensive term was therefore needed, and I think that the term "equilibrium curve," which is increasingly used by physicists, will be found to meet the case. Not only does the new term include the changes that occur after solidification, but it also tends to give greater precision to our views with respect to these changes. Thus a freezing-point, especially in the case of a solid solution, may vary in position, according to the degree of rapidity of the cooling; but a point of equilibrium shows the temperature and composition of a solution which is in permanent equilibrium with a certain solid—that is, no matter how long it is left, the amount of solid will neither increase nor decrease. The horizontal eutectic lines cannot be defined quite so simply, and have been omitted by some physicists; they are, however, an essential part of the system of curves, and connect together portions of the true equilibrium curves, which would otherwise be isolated. It will be evident, then, that in the case of the carburised iron series, we have two distinct systems of equilibrium curves: (1) that in which carbon is present in the form of graphite, and (2) that in which carbon is present in the form of cementite. We are acquainted so far with a part only of each system, namely, with the solidification of carburised iron on the graphite system, and with the allotropic changes on the cementite system; the converse—the solidification on the cementite system (forming white pig, and in some cases, possibly diamonds), and the allotropic changes of the graphite system (that is in very slowly cooled graphitic pig)—has yet to be studied.

The dotted lines occurring in Professor Roozeboom's Fig. 2 will probably represent the solidification of white cast iron—that is, they are parts of the cementite equilibrium curves, graphite being prevented from forming by pressure or by sudden cooling. A part at least of the horizontal line, EF, probably represents the separation of cementite at a constant temperature, from the solid solution of constant composition produced by the solidification of the graphite-iron eutectic, when sufficient time for the further separation of graphite is not allowed.

Plates XXI. and XXII. show the result of two of the experiments I made on the effect of prolonged annealing on carburised iron.

The iron was carburised by melting in a graphite crucible, packed in charcoal powder, and was subsequently annealed for nearly two days at a temperature below that of its melting-point, followed by very slow cooling.

Fig. 1 is the appearance under a low power objective, and represents with a magnification of 56 diameters a portion near the edge of the specimen. It will be observed that the lower part of the figure, which represents the superficial portion of the specimen, has a structure which is entirely different from the rest. A photograph of this portion under a higher power (1580 diameters), Fig. 2, shows ferrite with veins of graphite running through it. The inner portion appears in Fig. 1 to contain a considerable proportion of segregated cementite. A rough determination of the combined carbon by colour showed only about 0·4 per cent., and under the high power objective this portion (Fig. 3) appears to consist almost entirely of a badly developed variety of pearlite, with a little graphite and cementite. How can the different structures in the two portions of the metal be explained? It can scarcely be that the outer portion has been decarburised by cementation in charcoal powder, neither can we suppose that much more carbon has entered by cementation, seeing that it had already been fully carburised by melting in contact with charcoal. The explanation which appears to me to be the most probable one is, that the mechanical pressure which opposes the formation of graphite in the body of the specimen is considerably less near the surface graphite is consequently able to separate, and drains the combined carbon facing the surrounding iron, leaving almost pure ferrite. It is important to remember that the state of equilibrium of two or more bodies is affected by the pressure to which they are subjected, as well as by the temperature. We should, strictly speaking, have a succession of equilibrium curves, each corresponding to a particular pressure. The curves of Professor Roozeboom may well correspond to the true equilibrium of carburised iron when subjected to a considerable mechanical pressure, and that of Roberts-Austen to the somewhat mixed conditions which obtain in practice when both the temperature and the internal mechanical pressure are variable.

SUMMARY.

The general conclusions to be drawn from the inquiry appear to be :—

(1) That carbon is less soluble in iron when presented in the form of graphite than when presented in the form of cementite.

(2) That the apparent reversal of this in steel is due partly to the absence of nuclei of graphite on which further deposits might take place; partly to the length of time required for the separation of the graphite, involving, as it does, the gradual passage of carbon through the iron to reach the nuclei; and partly to the mechanical pressure which must oppose the formation of graphite in solid steel.

In conclusion, I wish to thank Sir William Roberts-Austen for the facilities he has placed at my disposal in connection with the experimental part of this paper, and Mr. E. O. Courtman, who prepared the sections and took the photographs.

CORRESPONDENCE.

Professor H. LE CHATELIER sent the following communication:—The work of Mr. Bakhuis-Roozeboom on the conditions of equilibrium between iron and carbon is of the highest importance. It is the first time that this question has been fully and fairly met in all its details in a rigorously scientific manner. Ultimately the work that remains to be accomplished will consist in evaluating the numerical values of the conditions, but no change will be made in the ideas founded on them and generally accepted. At the present time it is possible to commence the revision of the details in the light of certain experimental facts which were not known to the author.

1. The curve AB of the solidification of liquid iron given as continuous seems rather as if it should show an angular point, according to the experiments of Mannesmann as well as those more recent ones of Roberts-Austen. This point corresponds to a temperature of 1275° C. and to 2·25 per cent. of carbon. This should be the invariable point corresponding to the equilibrium of the three phases, liquid iron, martensite, and austenite.

2. Mr. Bakhuis-Roozeboom states that the curve AE relative to the equilibrium between the martensite and the graphite cuts the curve E′S at the point E. That is impossible; these two curves are practically parallel and the curve AE tends to intersect the bent line GOS in the neighbourhood of the point O. The line E′S along the whole of its length corresponds with unstable equilibrium. This follows from the observations of Forquignon, Arnold, Osmond, and Royston on the production of graphite during the annealing of steel and iron. The experiments of Mannesmann show that towards 700° C. the saturation of martensite in contact with graphite corresponds approximately with a percentage of 0·5 of carbon, while at the same temperature the equilibrium with cementite corresponds to a percentage which is practically double.

3. The angular point S, which is shown by Mr. Roozeboom as agreeing with previously published work, ought to be removed

and to be replaced by a small element of curve between two adjacent angular points. As a matter of fact, the writer has shown, by measuring the dilatation, that the phenomena of recalescence is not a simple one, as has been previously considered, but is composed of two successive but entirely distinct phenomena. Experiments on hardening have established that pearlite first changes to troostite, a solid solution of carbon, probably magnetic, and afterwards at a point about 30° higher the troostite is transformed into martensite. There should therefore be a branch of the curve corresponding to the equilibrium of troostite with the martensite.

On the whole, and in fundamental matters, the writer is entirely in accord with Mr. Bakhuis-Roozeboom on the method of representing the phenomena of equilibrium, but he is not convinced, however, that it would not be of interest to duplicate the diagrams in order to render them more easily comprehensible by people who are less familiar with the phase doctrine. On one and the same figure there are curves representative of the composition of different phases of the liquid iron and of the martensite, to which for the sake of completeness the curves of austenite and troostite will also have to be added. That would make it too complicated unless different colours were employed to differentiate the curves. Such a course would give rise to difficulties in printing, and it would be preferable to have distinct figures for each phase, and to place them side by side, in order that the same horizontal line in each will show, as in the author's diagram, the composition of phases in equilibrium amongst themselves. The writer has given an example of this method of representation in an article on the phase doctrine published in the *Revue Generale des Sciences* (vol. x. p. 759) last year.*

Among the consequences of the theory developed by Mr. Bakhuis-Roozeboom there is one which requires some reservations. He indicates that iron of the composition represented by the point g would first give crystals of martensite lower in carbon shown by the point p. In consequence the iron would become richer in carbon and its melting-point would be lowered. This is rigorously exact, but the alteration in composition and the lowering of temperature only appears at the point represented by the iron *s* corresponding to a martensite *p* of the composition identical with that of the iron placed above it. This conclusion, exact in theory, could not always be verified in practice. It supposes that the carbon diffuses in the martensite in such a way that in the centre of the solid mass the crystals first deposited would be constantly enriched in carbon, so as to remain always in equilibrium with the liquid iron. That is true, provided that the cooling takes place very slowly, so as to permit the diffusion of the carbon through the solid mass. If the cooling is not sufficiently slow, the composition of the iron may descend below the point *s*, and may even reach the eutectic B′. Matters often seem to progress in this way, as is shown by the appended photograph, which is magnified 700 diameters. The white triangle is the eutectic B′. All around it the pearlite is much more condensed than at a small distance from it. This indicates that the martensite from which it originated had not everywhere a uniform composition.

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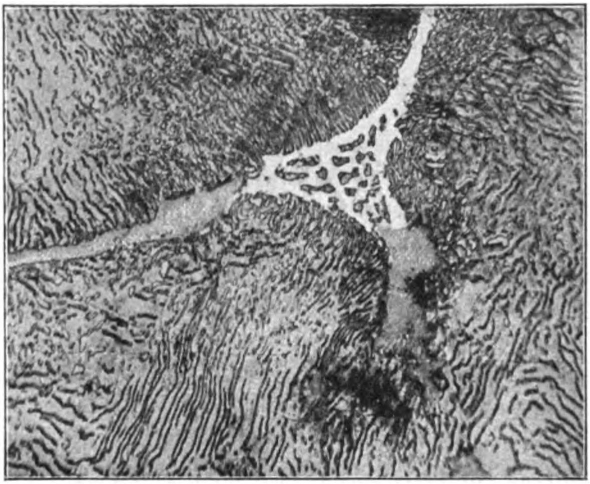
* See also *Bulletin de la Société d'Encouragement*, vol. vi. 1900, p. 661.



Baron H. VON JÜPTNER sent the following contribution to the discussion of papers by Professor Backhuis-Roozeboom and Mr. A. Stansfield:—

The autumn meeting of the Iron and Steel Institute of 1900 is an important landmark in the development of our knowledge of the theory of iron-carbon alloys.

It is very gratifying to see that at this meeting a hitherto unprecedented number of theoretical papers appeared, and that interest in the purely scientific treatment of the steel industry (taken in its broadest sense)—that is to say, interest in a scientific treatment of all questions pertaining to iron—is constantly increasing. Moreover, it is of quite peculiar importance that so celebrated a physical chemist as Roozeboom should have turned his attention to this question, and that in his admirable paper, "Iron and Steel from the Point of View of the 'Phase Doctrine,'" he has at least reached certain preliminary conclusions.

The question now remains whether, by means of discussing in detail the picture sketched for us by Roozeboom, which, unfortunately, is founded upon very few observations, we shall be able to attain to certain possibilities in other directions. This is the more important, as by this means those questions which are before us, and which can be answered by experimental work, become more exactly determined.

The problems which appear in this branch of experimental work are most certainly of the greatest importance and full of promise, especially as theory has now shown us the way in which these may be further extended.

The wish of directing experimental work more into this difficult region was the cause of my first publications on the "application of the solution theory to iron alloys." *

Although I knew that the material at hand was in no way sufficient for the complete theoretical treatment of the subject, yet I made it my aim, so far as circumstances permitted, to produce a sketch which as nearly as possible represented the observations made. I wished at the same time to offer suggestions for further work, both on the theoretical and practical side,

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* For quite a number of years suggestions have been found in the literature of the subject that iron alloys may be considered as solutions. The first papers in which these views were distinctly formulated were, so far as I know, by H. Le Chatelier (*Rev. Gén. des Sciences*, Jan. 15, 1897) and by the present author (*Baumaterialienkunde*, 1897, ii. 5 and 6). The former first came to my knowledge through *The Metallographist* (1898, No. 2). To these may be further added the work carried out by Roozeboom (*Zeitschrift für Phys. Chemie*, xxxiv. 4, p. 437).

and am therefore greatly pleased that this happy result has followed.

In the present paper I should like to dwell upon several points in Roozeboom's beautiful work, in which my views will be set forth after a discussion of the case, and also to touch upon Stansfield's new and interesting publication.

As in the most important part of Roozeboom's paper austenite was not taken into consideration, in the present paper I have chosen the less definite expression "mixed crystals," instead of the expression "martensite mixture of crystals," so as not to anticipate the determination of the boundaries between martensite and austenite, which have not yet been definitely determined.

I. SEQUENCE OF EVENTS ON SOLIDIFICATION.

1. The position of the point *a*, which naturally determines the whole course of the curve *Aa*, will first have to be accurately determined experimentally. In the meantime, this point in Roozeboom's Fig. 2 can quite well be taken as accurate.*

According to the original data, the point *a* lies at 1·2 per cent. of carbon. If one considers that at 1130° C. the quantity of heat liberated must become proportionately less the smaller the quantity of mother-liquor present which solidifies at this temperature, so it is always possible that the point *a* may correspond to an even smaller percentage of carbon than 1·2.

On the other hand, it is also possible that the point *a* lies to the right of 1·2 per cent. of carbon, since on solidification, if this does not take place too slowly, it is not impossible that no complete equalisation of the amount of carbon present in the mixed crystals separated from time to time takes place. If an alloy with less than 4·3 per cent. of carbon begins to solidify, mixed crystals with a definite but lower percentage of carbon than the melt itself are separated. In this case the residual liquid portion and also the mixed crystals separated from the same at a lower temperature must contain a higher percentage of carbon.

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* The contrary view, taken by Stansfield in his paper, "The Present Position of the Solution Theory of Carburised Iron," Part 2, I cannot at present take into consideration, as in the Le Chatelier formulæ used by him the details of the data are missing, and it is consequently impossible to prove either these or the modifications of them introduced by Stansfield.

If one finds from the amount of carbon present in the separated portions at different intervals following one another, which portions (according to Stansfield's views) will form a series of shells one over the other, so that either no equalisation takes place or the equalisation is incomplete, then the temperature of the end of the process of solidification will be lowered, and if at the same time the eutectic temperature be reached, there must be larger quantities of the eutectic alloy present than if complete equalisation had taken place. Under this assumption the observed position of the point *a* must lie to the left of that theoretically assigned to it.

Backhuis-Roozeboom has dealt with the case in which there is complete equilibrium between the separated masses of crystals and the solution. I have taken the directly opposite case, viz., that in which no equalisation of carbon takes place between any two consecutively separated masses of crystals, and that the mother-liquor is in equilibrium only with the portion which last separates, a conception which I have convinced myself by investigating an ideal special case, approximately corresponding to that of very quick cooling, just as Roozeboom's assumption closely corresponds to the conditions obtaining during very slow cooling.

If we assume that the curve *Aa* is rectilinear, whilst the curve *AB* (as Roozeboom indicates, and as also appears to be shown by the data obtained from the researches of Roberts-Austen) is made up of two straight lines which meet at 1250° C. and 2·7 per cent. of carbon[*] (point *s*), and if we designate the tangents of the angles these lines form with the axis of temperature as follows:—

As with a
sB ,, a_1
Aa ,, b

and also the melting-point of pure iron with T, the point of incipient separation with t_1, and the temperature which must be determined for whatever the quantity of iron still remaining liquid with t_1, then every portion which still remains liquid at the temperature t_1 is represented by the formula—

$$P = \left(\frac{T-t}{T-t_1}\right)^{\overline{a-b}},$$

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[*] Any other position of the curves, so long as they remain rectilinear, would only alter the constants whilst allowing the general character of the formula to remain unaltered.

in which expression for temperatures between 1600° and 1250° C. $\frac{a}{a-b}$ is approximately equal to 2.

For lower temperatures the portion remaining fluid at the bend in the curve must be determined; the calculation then follows according to the equation

$$P_1 = P_{1250}\left(\frac{143}{1393 - t_2}\right)^{\frac{a_1}{a_1 - b}},$$

in which $\frac{a_1}{a_1 - b}$ is very close to 1·4.

Though the values of a, a_1, and b deduced from the graphic construction are certainly not exact, yet an accurate calculation of the process of cooling was undertaken, since even in the event of inaccurate data the general course of the separation, and with it the observed curves of cooling, remain unaltered, and the object of this calculation was only to show to what extent the position of the solidifying point, the proportion of matter separated, as well as the heat liberated in the process, underwent alteration on this assumption.

Between this extreme case and the other of complete equalisation, for which the calculations were also made according to the directions of Roozeboom, the actually observed value must lie, its position depending upon the rapidity of cooling.

(*a*) *Steel with* 0·5 *per cent. Carbon.*

Temperature in °C.	Fluid Residue (P).		$\frac{dP}{dT}$		Remarks.
	Without	With	Without	With	
	Equalisation of carbon of the mixed crystals.				
1535	100·00	100·00	0·03100	0·0309	Beginning of solidification.
1525	74·48	71·79	0·02001	0·0232	
1515	57·91	50·64	0·01373	0·0181	
1505	46·24	34·19	0·00981	0·0145	
1495	37·83	21·03	0·00726	0·0118	
1485	31·49	10·26	0·00552	0·0099	
1475	26·62	0·22	0·00429	0·0084	
1450	18·43	...	0·00248	...	
1400	10·33	...	0·00104	...	
1350	6·59	...	0·00056	...	
1300	4·55	...	0·00030	...	
1250	3·34	...	0·00019	...	Point of change.
1130	1·26	...	0·00007	...	Eutectic alloys.

(*b*) *Iron with* 2 *per cent. Carbon.*

Temperature in °C.	Fluid Residue (P).		$\frac{dP}{dT}$		Remarks.
	Without	With	Without	With	
	Equalisation of carbon of the mixed crystals.				
1340·74	100·00	100·00	0·007772	0·007773	Commencement of solidification.
1330	92·15	91·98	0·006877	0·007166	
1320	85·64	85·08	0·006162	0·006663	
1310	79·09	78·64	0·005495	0·006212	
1300	74·52	72·64	0·005005	0·005804	
1290	69·44	67·03	0·004513	0·005436	
1280	65·43	60·52	0·004120	0·005102	
1270	61·50	55·43	0·003755	0·004797	
1260	57·91	50·70	0·003432	0·004519	
1250	54·62	46·22	{ 0·003144 0·005348	0·004264 0·006191	Change in the curve.
1240	49·68	42·84	0·004551	0·005411	
1230	45·46	37·76	0·003908	0·004770	
1220	41·82	33·26	0·003389	0·004236	
1210	38·66	29·26	0·002961	0·003787	
1200	35·88	25·67	0·002606	0·003406	
1190	33·43	22·43	0·002308	0·003080	
1180	31·25	19·49	0·002057	0·002798	
1170	29·30	16·82	0·001842	0·002554	
1160	27·55	14·37	0·001658	0·002340	
1150	25·98	12·13	0·001499	0·002151	
1140	24·55	10·06	0·001360	0·001979	
1130	23·25	8·15	0·001240	0·001837	Eutectic alloy.

From the figures in the tables we see that which is also self-evident according to the given formula, that by prevention of equalisation even with a lower percentage of carbon, a small portion of the solution only becomes solid at the solidifying point of the eutectic alloy. If, however, this extreme case is not attainable in practice, yet it is evident that a considerable increase in the intervals of solidification will be observed. In this case one would from such observations erroneously construct a lengthening of the eutectic line *aBC*, a mistake which may possibly already have been made. In the case of alloys whose solidification-intervals, even with complete equalisation of carbon of the mixed crystals, continues as far as the melting-point of the eutectic alloy, the quantity of the latter becomes naturally considerably increased.

While the foregoing considerations refer chiefly to the quantitative proportions of the substances which separate, certain other conclusions may be drawn as to the curves of cooling from the formula for the separation. After the determination of the real curves of cooling, the excess of heat is measured which the substance under experiment gives in consequence of its change of state, compared with one which undergoes no similar change; and as in all cases examined, the heat of fusion of the substance which separates is the cause of this evolution of heat, we are able, under the restricted assumption to which we are led of the heat of melting being but slightly variable, to put the evolution of heat as proportional to the quantity of material separated.

The alteration in direction which a curve of cooling in a given interval of temperature experiences is dependent upon the quantity of matter which separates in this same interval of temperature, and can be expressed by $\frac{dP}{dT}$.

The greater this value is, so much the more sharply must the variation of the curve of cooling separate from that obtained for a substance which cools down without change of state.

From the values calculated for $\frac{dP}{dT}$ in the two cases, we can deduce the following. The commencement of solidification corresponds to the maximum of the alteration of direction, and even in cooling under both the above conditions is quite sharply marked. Referred to this point the observations can scarcely lead to error. The value of $\frac{dP}{dT}$ diminishes with the temperature. This diminution is much more rapid in the case of cooling without equalisation of carbon, and therefore curves must result which give no exact impression of the course of events; afterwards the deviations of the curve from the normal one are only quite trifling. But even in the case of complete equalisation of carbon, that is, in the case of slow cooling, the end of the curve is very indefinite.

We must at once exclude the assumption that the point of change in the curve *AB* given by Roozeboom corresponds to a sudden increase in the value of $\frac{dP}{dT}$. Since, unfortunately, custom does not permit the publication of temperatures measured, times, &c., but only the curves derived from these observations, I am not in a position to check these results. Should, however, the experimental results afford no confirmation of this assumption, then either the point of change in the curve *AB* does not exist, or the curve *Aa* must also have a corresponding change of direction, which would agree with Stansfield's published view of the case.

2. By completely undisturbed cooling the possibility of supercooling is, moreover, not excluded. In this case, however (as, for example, was observed in the case of tin by Roberts-Austen), the temperature must rise at the actual moment of solidification. Since, however, the composition of the mixed crystals is a function of the temperature, its composition may vary somewhat when supercooling ceases, and thus the secondary maximum of temperature which is observed in cases of supercooling may be lowered, and this maximum will only approximately correspond to the temperature sought.

The possibility of retarded solidification through incomplete equalisation of the mixed crystals renders a determination of the whole interval of solidification by means of fixing the beginning of solidification during cooling and the beginning of fusion during heating impracticable, for, as we have seen, although the temperature of the beginning of solidification can be approximately determined, the temperature at which fusion commences is less certain.

For instance, if the equalisation of carbon in the mixed crystals be incomplete, as is probable, the portions of solution which solidify last will contain a greater proportion of carbon and possess a lower solidifying-point than if complete equalisation were the case, and the point of incipient fusion would appear too low. Further, in the case of incomplete equalisation, the number of portions richest in carbon is small, and so the temperature of incipient fusion will not be sharply marked.

3. In a similar manner to that of the mixed crystals, starting on the assumption that graphite is pure carbon, we can calculate the amount of graphite which separates during the cooling of molten iron containing more than 4·3 per cent. of carbon. In Fig. 1, *BD* is the separation-curve of graphite from molten iron, *BC* the eutectic line, t the melting-point of an alloy containing p per cent. of carbon, and t_1 the temperature for which the separation of the graphite has to be calculated; then qt is the

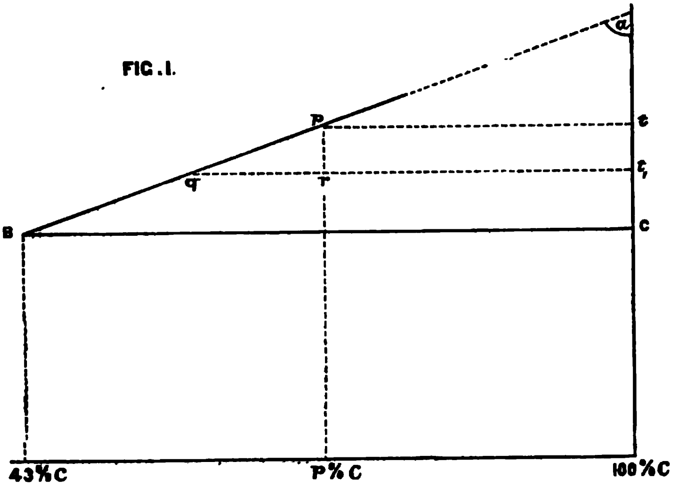
quantity of the alloy dealt with, and qr the quantity of graphite separated, P, and therefore—

$$P = \frac{qr}{qt_1} = \frac{(t - t_1)\ tqa}{(100 - p) + (t - t_1)\ tqa.}$$

Here, again, the amount of graphite separated will be greatest at the first moment of cooling, and will diminish by further cooling.

This diminution will, however (since $100 - p$ is much larger than $(t - t_1)\ tqa$), be so small that we can assume with sufficient accuracy that the separation of graphite is directly proportional to the decrease in temperature. Hence in the case of iron-carbon alloys with 4·3 per cent. of carbon, the point of the eutectic temperature will be less sharply marked than in the case of alloys containing less carbon.

FIG. I.



4. Stansfield * has brought forward the hypothesis that about one-half of the carbon dissolved in iron separates on cooling, and uses an equation of Le Chatelier's modified by himself. Unfortunately, it is not stated where the original formula is to be found, and to what extent the modification is justified, so that in this case any discussion is impossible.

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* "The Present Position of the Solution-Theory of Carburised Iron" (*Journal of the Iron and Steel Institute*, 1899, No. II. p. 169, and this volume, p. 317).

5. In order to explain the changes which take place on quick solidification, Roozeboom has lengthened the line AB to B_1, also he has drawn the eutectic line E_1F_1, and further, by means of the line B_1D_1, has pointed out that in this case the eutectic alloy would appear at about 5½ per cent. of carbon. Of course this case can only happen if quick cooling first takes place, not at the solidifying point, but at a higher temperature (that is, at the corresponding point of the line BD).

II. CHANGES BETWEEN 1130° AND ABOUT 1000° C.

1. Roozeboom starts with the assumption that the solidified metal at 1130° C. consists of a conglomerate of mixed crystals containing about 2 per cent. of dissolved carbon and of graphite, in which it is not necessary to assume that the dissolved carbon is also present as graphite.

The solubility of carbon in iron probably decreases with the temperature.

This fact he indicates by means of the line aE, along which a separation of carbon (either graphite or temper carbon) takes place from the mixed crystals. He places the point E at 1000° C. and 1·8 per cent. of carbon, so as to allow it to coincide with the end-point of Roberts-Austen's curve for the separation of cementite.

This assumption is not in complete agreement with fact. For example, Ledebur has determined the composition of a steel heated for a long time as follows:—

	Per Cent.	
Temper carbon	0·17	1·20 p.c.
Carbide carbon	0·90	
Hardening carbon	0·13	
Silicon	0·79	
Manganese	0·40	
Phosphorus	0·07	

If we calculate the silicon present (0·79 per cent.) into its equivalent amount of carbon (0·34 per cent.), we have a total of 1·54 per cent. of carbon. The author has likewise found, in a steel with 0·21 per cent. of silicon—

	Per Cent.	
Temper carbon	0·58	0·95 p.c.
Combined carbon	0·37	

It therefore appears that the end-point *E* of the curve *aE* must be placed rather more to the left.

Similarly, Ledebur found that a white pig iron which originally contained no graphite contained after heating for 108 hours—

	Per Cent.	
Temper carbon	1·55	2·29 p.c.
Combined carbon	0·74	
Silicon	0·87	
Manganese	0·10	

Since 0·87 per cent. of silicon is equivalent to 0·37 per cent. of carbon, in this case we have a theoretical amount of total carbon of 2·66 per cent., which is certainly higher than Roozeboom's limit value (1·8 per cent.), but the quantity of separated temper carbon is so considerable that this analysis also appears to favour the shifting of the point *E* previously mentioned.

As we shall see later on, the separation of temper-carbon in the cases we have dealt with may be referred to other causes, so that the position of the point in question may well be possible at 1·8 per cent. of carbon. Circumstances to be dealt with later, however, appear to indicate that the point should be taken for a lower percentage of carbon.

2. According to Roozeboom, another change takes place at about 1000° C., in which the graphite enters into combination with the mixed crystals containing 1·8 per cent. of carbon to produce a carbide (Fe_3C). He indicates this change by the horizontal line *EH* drawn at about 1000° C.

As a matter of fact, Roberts-Austen has found in two experiments retardations in the neighbourhood of this temperature, viz.—

With 2·7 per cent. carbon 1040° C.
With 4·5 per cent. carbon 1000° C.

Further, Osmond and Werth* have already found similar retardations in very different classes of raw iron, as follows:—

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* *Etudes metallurgique; Annales des Mines*, 1888, July-August.

	Hæmatite Pig Iron.	Foundry Pig Iron.	Thomas Pig Iron.	Ferro-manganese.	Ferro-mangauese.	Ferro-manganese.	Silico Spiegel.
Total carbon . .	3·29	...	2·70	...	...	...	2·53
Combined carbon .	1·04	...	1·20	5·10	5·00	4·80	...
Graphite . . .	2·25	...	1·50	...	...	...	...
Silicon . . .	2·45	2·13	1·89	0·71	0·43	0·80	12·90
Sulphur . . .	0·061	0·042	0·03	0·65	...	...	...
Phosphorus . .	0·054	0·16	1·98	...	0·11	0·098	0·22
Manganese . .	0·11	2·12	0·74	80·96	48·95	16·79	24·55
Iron	...	...	...	13·16	45·51	77·51	...
Solidification point .	1240?	1230?	...	1210	1145	1083	1220
Retardation point I.	1115–1165	1085–1130	1060–1070	1150–1160	1100–1110	1030–1063	1055–1045
,, ,, II.	1077–1091	1050–1089	1080–1000	1080–1100?	1015–1030	...	975–985
,, ,, III.	...	...	891–900	975	910–920	...	940–950

Retardation-point I. is easily identified with the solidifying-point of the eutectic alloy. Its mean value is above 1100° C., but is naturally influenced by the presence of other elements. In the case of ferro-manganese, with 16 per cent. of manganese, it is quite conceivable that the melting-point given (1080°) could coincide with the solidifying point of the eutectic alloy. Retardation-point II. would correspond with Roozeboom's questionable point of change. It is wanting in the case of ferro-manganese with 16 per cent. of manganese (unless, from the considerations given above, there is the possibility that retardation-point I. is to be considered as this point of change). Although the existence of the curve *EH* seems to be proved, yet this must lie above 1000° C., since the mean of the above values gives 1040° C.*

3. The assumption made by Roozeboom that a reaction takes place between the mixed crystals and the graphite is theoretically completely justifiable; but as both he and Stansfield in his paper of this year remark, it finds no support in facts, according to which, cast iron on being quietly cooled, separates no graphite, while, by more gradual cooling, it contains considerable amounts of this substance. We shall return to this point in the next section.

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* Possibly these points correspond with Roozeboom's line E_1H_1.

III. CHANGES TAKING PLACE IN IRON ALLOYS RICHER IN CARBON BETWEEN ABOUT 1000° AND 690° C.

1. The facts quoted above are directly opposed to the assumptions of Roozeboom. According to Stansfield, in iron alloys containing a large proportion of carbon, either graphite or cementite alone is found, while the other of these two constituents is present in negligible quantity. This agrees completely with the phase rule, since the small quantity of the second substance is easily explained by considerations of retardation. Stansfield rightly concludes that, under the conditions obtaining, graphite is the more stable form, which is also supported by the experiment of strongly heating cast iron which originally contained cementite and graphite.

The absence of graphite in most kinds of steel, even after heating, is explained by him (Stansfield) as follows:—A solid solution of carbon in iron, even if considerably supersaturated, does not deposit graphite easily, because as soon as the saturation-point is reached cementite at once separates. The reason for this is, according to his views, that the presence of graphite (from the eutectic alloy), which in iron alloys rich in carbon assists in the separation of graphite, and conversely its absence in iron solutions containing less carbon, acts as an internal pressure to prevent the separation of graphite.

2. Stansfield adduces the following experiment:—Iron was melted together with charcoal powder in a graphite crucible for two days, then heated for one day at a temperature below the melting-point, and then allowed to cool very gradually. The external portion contained ferrite mixed with veins of graphite; the internal portion (slightly magnified) appeared to contain considerable quantities of cementite. A colour-carbon determination gave, however, only 0·4 per cent. of carbon; under a higher power the main portion was recognised as badly developed pearlite mixed with a little graphite and cementite.

An experiment of Ledebur's throws light upon this point. He heated a piece of cast iron containing 2·52 per cent. of carbon, and a piece of malleable iron containing 0·16 per cent. of carbon, both being well packed in wood charcoal in the same crucible. After the heating, the former was found to contain

2·37 per cent. of carbon and the latter 0·69 per cent. From this it is seen that heating an iron alloy in charcoal may either increase or decrease the amount of carbon in the iron. This is only what might have been expected, since iron in contact with solid carbon must have a tendency to reach a state of equilibrium dependent upon the temperature. If the cooling process could be made infinitely long, the end result, at a temperature at which carbon is quite insoluble in iron (690°) would be iron free from carbon.

In this lies the explanation of phenomena with which we have here to deal, phenomena which, by a research of Saniter's, are illustrated in a most beautiful manner. He heated pure carbide of iron to different temperatures and investigated the product obtained after both quick and slow cooling. He found—

	Iron.	Combined Carbon.	Graphite.	Total Carbon.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Heated to 800°: slowly cooled . .	93·41	5·72	0·40	6·12
" 1000°: quickly " . .	92·6	5·57	0·56	6·13
" 1000°: slowly " . .	92·85	3·71	2·46	6·17
Melted at 1400°: " " . .	95·40	1·22	3·05	4·27

These experiments show that at higher temperatures the carbide constantly becomes the more decomposed (obviously the carbon thus separated will go into solution according to the temperature attained), and that (agreeing with the decrease in solubility at a lower temperature) on slower cooling the liberated carbon (in spite of the presence of cementite) is able to separate as graphite. On the contrary, if the cooling is rapid the carbon remains dissolved and the metal becomes white.

These experiments also give a point which is of importance in fixing our curves of equilibrium, viz., the exact composition of the eutectic alloy, since molten cementite containing 6·67 per cent. of carbon, on very gradual solidification, has sufficient time to allow all the graphite deposited above 1130° to separate as a kind of scum.

3. Different kinds of iron, rich in carbon and containing graphite, behave, on slow cooling, exactly in the same way as carburised irons in contact with carbon when the latter are cooled extremely

slowly. In this case also we have a solution of carbon in iron in contact with more carbon (viz., the graphite separated), and the dissolved graphite will, in the course of cooling, tend to deposit on the particles of graphite.

The active force is in both cases osmotic pressure, and decarburisation takes place more quickly the greater this force is (that is to say, the higher the temperature and the greater the concentration), the larger the surface of contact between the carburised iron and the graphite (that is to say, the greater the quantity of graphite already separated). On the other hand, decarburisation is limited both by the temperature and by the degree of saturation of the iron.

The decarburisation can, of course, only become complete and attain a condition of stable equilibrium when the cooling is exceedingly slow; yet it is quite certain that loss of carbon must begin immediately the smallest quantity of graphite appears in the alloy, and when the temperature falls so far that the iron carbon solution is super-saturated.

If we consider that, according to Roozeboom, martensite, even at high temperatures, deposits graphite, represented by the course of the line *aE*, then it is clear that the separation of graphite, which takes place under 1000°, will be represented by the line *aE* produced.*

4. In order to determine the position of this line more accurately, we have to bear in mind that if steel is heated for a long time to a sufficiently high temperature it deposits its temper-carbon, which within the temperature-interval mentioned, viz., 1000° (or 1030° C.), can neither pass back again into solution nor yet become transformed into carbide. Within this doubtful zone-temperature the free carbon is in a stable condition. From this it follows that the curve of carbon-separation runs from the right at the top to the left at the bottom, and must be placed to the right of and below the cementite curve *SE*.†

In order to exactly determine the position of the curve we will endeavour to fix two points upon it. The point *E* must be upon the line of the separation of graphite EF_1, which, according to Roozeboom, is at about 1000° C., or, according to our conditions, at 1030° (or 1040° C.). At a temperature of 1030° the solubility of carbon in iron may with considerable certainty be taken to be 1·5 per cent. as determined by Royston's* very thorough experiments.†

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* Assuming that temper-carbon and graphite have the same coefficient of solubility.

† Stansfield has drawn the curve (aS_1) above and to the left of *SE*. According to this supposition cementite would be the more stable condition, which is contradicted by the above facts.

Another point on the curve in question can also be determined with a fair amount of certainty. Mannesmann, by treating together soft iron and wood charcoal (at a bright red heat, according to Taylor 740° C.), reached a state of equilibrium at 1·20 per cent. of carbon after thirteen days. Saniter, by heating cementite and after gradual cooling, found 1·22 per cent. of combined carbon. Royston found at 720° equilibrium at 1·20 per cent. of carbon, and at 670° at 1·10 per cent. From this we shall certainly not be much in error if we assume the point of equilibrium at a temperature of 690° (Ar_1) at 1·10 per cent. of carbon.

5. If we join the two points determined as above by means of a straight line and produce the same upwards, it will cut the eutectic temperature-line (1130° C.) at 1·60 per cent. of carbon, which to some extent supports the possibility that the point, instead of being at 2 per cent. of carbon (Roozeboom), lies at 1·60 per cent.

If, however, we take into consideration, as Roozeboom does, the possibility of the formation of austenite below 1130°, the point may still be at 2 per cent. of carbon. With reference to the curve *SE*, I should here like to remark that, although it is true that only very few points upon it have up to now been determined, so that an exact determination of its position is at present unable to be made, yet the few points upon it determined at present appear to indicate that the lower portion of the curve, starting from the point *S* (which perhaps would be better taken at 0·86 per cent. of carbon, since in the fifth Report to the Alloys Research Committee it was placed at 0·82 per cent.), appears to run in a straight line, as do most of the other curves in the graphic construction. At about 900° C. the curve seems to have a kink. Should it after this point again become rectilinear there are two possibilities to hand. If we alter Roozeboom's line *EF*, on the grounds previously mentioned, to about 1030° C., the line of cementite separation will cut it at 1·5 per cent. of carbon (instead of 1·80 per cent.). On the other hand, if we take the change martensite + graphite = cementite, and continue the curve of the separation of cementite through this point of change, and through the nearest point determined by Roberts-Austen, and we reach the temperature 1300° at about 1·7 per cent. of carbon. This would indicate that between 1000° and 1030° C. the cementite was the stable condition, whilst below 1000° the graphite would be the more stable. With respect to the point experimentally determined by Roberts-Austen, we prefer, until more experimental results are obtained to assume the latter.

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* *Journal of the Iron and Steel Institute*, 1897, No. I. p. 166.

† By this the end-point of the horizontal line *EF* would be changed from 1·80 per cent. of carbon to 1·50 per cent.

6. The lines *PO*, *MO*, *OS*, *SE*, and *PS* represent the conditions of equilibrium existing between iron and carbide of iron; the conditions of equilibrium existing between iron and carbon must be altogether similar. *ES* we have already determined with a fair amount of accuracy. From the various studies made of cementite, it appears that the eutectic point S_1 at this same temperature (690°) lies near the point *S*, so that for the present we can take the eutectic line *PSK* as being the same for both states of equilibrium. The points *G* and *M* must remain the same, so that we can well attempt to represent the curve of ferrite separation connected with them by means of the lines GO_1, MO_1, O_1S_1 (Fig. 2; in which, of course, the position of the point O_1 is quite hypothetical).

The course of the curves thus drawn corresponds with the assumption that the condition of equilibrium represented in this manner is less stable than that corresponding to the curves of Roberts-Austen. In any case, the results of further experiments must be waited for before the positions of these lines can be more accurately fixed.

7. The conditions of the non-formation of cementite which occur during very slow cooling, and which have already been considered, also explain the formation of temper-carbon by the long-continued heating of steel. On sufficiently long heating, either a direct isothermal conversion of cementite into graphite

takes place, or, if the heating reaches the temperature indicated by the intersection of the lines ES and aS_1, on gradual cooling the direct separation of graphite is able to take place.

IV. CHANGES IN SOLID MIXTURES CONTAINING LESS THAN 2 PER CENT. OF CARBON.

Roozeboom in his paper "Iron and Steel from the Point of View of the Phase-Doctrine,"[*] points out the possibility that not only γ-iron, but also the β- and α- modifications—the two last to a lesser degree than the first—may be capable of containing dissolved carbon even at low temperatures.

That this case is quite possible, and certain facts appear to speak in its favour, renders it very desirable that the question should be thoroughly investigated.

Other points bearing upon this question have already been mentioned.

V. CHANGES IN CARBURISED IRON AT 690° C.

I must here allude to the possibility that under certain conditions at present unknown, at a temperature not far removed from 690° C., the conversion of martensite into ferrite and graphite may take place. It would correspond to the equilibrium existing between iron and carbon.

VI. OTHER CONSTITUENTS.

According to Roozeboom, sorbite and troostite cannot at present be brought within the system. I believe this to be scarcely necessary, since these substances are apparently only transitional ones, and may well be dealt with as phenomena of retardation. Of much greater importance is the austenite. Roozeboom also recognises this, since he (in his full paper in the *Zeitschrift für Physikalische Chemie*) attempts in Figs. 5 and 6 to bring this substance also into the system of equilibrium. I will not enter into the matter here, since all experiments that have been made with austenite up to the present are far too incomplete to be subjected to criticism; but the importance of austenite in getting a clear view of the conditions of equilibrium must be fully recognised, since previous considerations having shown what an influence the conditions of cooling produce on the state of equilibrium at higher temperatures, that similar conditions must obtain in the case of lower temperatures.

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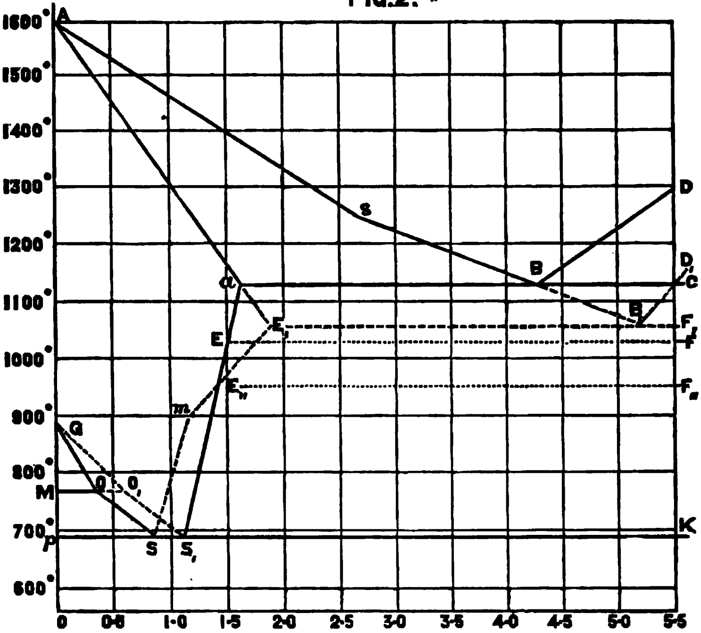
[*] *Zeitschrift für Phys. Chemie*, vol. xxxiv. p. 471.

VII. INFLUENCE OF VARIOUS COOLING PROCESSES ON THE CONDITIONS OF EQUILIBRIUM.

FIG.2.[*]



The curves already considered have been obtained by the consideration of an ideal stable equilibrium, which, in the case of iron alloys, can be obtained in practice only with the greatest difficulty by extremely gradual cooling. From consideration of the curves *AB* and *Aa*, we have already seen how through quick cooling, which prevents the complete equalisation of carbon between the mixed crystals separated at different temperatures, alterations take place in the relative proportions.

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[*] This figure depends upon the points previously determined. In cases where several possibilities are present, only one is considered, for the sake of clearness. The stable conditions are drawn in lines, the meta-stable (transitional) ones in dashes, and the somewhat doubtful line of change, EF (corresponding to $E_{\prime\prime}F_{\prime\prime}$), merely dotted.

In the case of sufficiently quick cooling, the solidifying-point *B* will be moved to B_1, by which the position and constitution of the eutectic point must also be moved.

If the cooling is gradually continued till everything has solidified, the solid mass consists of a mixture of mixed crystals having the composition *a* and of graphite, and by further continued and more gradual cooling the separation of graphite takes place along the line aS_1. At the temperature S_1 the remaining martensite can be changed either into a mixture of iron and cementite or a conglomerate of ferrite and graphite.

Should, however, the complete soldification have been lowered by quick cooling to the line E_1F_1, the result of this procedure will probably be (at least in the case of not more than about 5 per cent. of carbon) not a mixture of mixed crystals having the composition *a* together with graphite, but a conglomerate of mixed crystals having the composition E_1 together with cementite. On further (quicker) cooling, no graphite separates, but only cementite (along the line E_1mS).*

If, on the other hand, as has previously been assumed, the solidification follows a course corresponding to the line *aC*—that is to say, slowly—and if from this point further cooling takes place at a medium rate of speed, then it follows that with a low percentage of carbon (under 1·4), the graphite separation takes place along the line $aE_{\prime\prime}$, and the cementite separation along the line $E_{\prime\prime}mS$; or with a still lower percentage of carbon, ferrite separation along the lines *GO* and *OS*. Should the cooling take place more rapidly, the separation of cementite and of ferrite does not take place, and we have below *PSK* martensite produced (hardened steel).

We must not lose sight of the fact that, just as by the equilibrium between iron and iron carbide along the line *PSK*, martensite is changed into pearlite (a mixture of ferrite and cementite), so by the equilibrium between iron and carbon, the conversion of martensite into a mixture of ferrite and graphite is conceivable. Whether, and under what conditions, this process is capable of realisation, further experiment will show.

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* On very gradual cooling graphite (or temper-carbon) would be capable of separation only below $E_{\prime\prime}$.

The sequence of events on heating is naturally the reverse of those on cooling. Thus heating to a little over 690° suffices to convert steel hardened (that is to say, containing martensite), if followed by slow cooling, into steel containing pearlite.

If steel containing separated cementite is heated, then, as has been seen previously, one of two things must take place; either the cementite may be converted isothermally into graphite, or else it may go into solution, whence, on slow cooling, it may be again separated as cementite, as, in consequence of the presence of such small quantities of cementite, the separation of this form is necessitated.

In this case, the separation of carbon can only take place if, on heating the temperature, E_1 has been attained. Whether this is really the case depends upon the circumstance whether, at the first moment of solidification, graphite or cementite is separated. The case is then quite analogous to the behaviour of a solution of sodium sulphate, which, according to whether it is brought into contact with crystals of Na_2SO_4, $10H_2O$, or Na_2SO_4, $7H_2O$, separates different salts from the same solution.

After our views of metallic alloys, and especially of iron-carbon alloys, have been so greatly extended by means of theoretical and physical chemistry, the experimentalist comes once more to the front, in order—it may be by means of a fundamental study of curves of cooling, of dilatation, &c., or through the application in this direction of various chemical and microscopical researches—to determine, so far as possible, the exact position of various points of change and curves deduced from them, and also the numerical data that these give rise to.

These experiments must certainly be frequently repeated under varying conditions, especially as regards time, since it is very possible, especially in the chemistry of iron, that meta-stable (transitional) conditions occur, and only experiments frequently repeated, and extending over a long period of time, will yield a satisfactory result.

DR. A. STANSFIELD, in reply to the correspondence on his paper, wrote:—"I am highly gratified that my paper should have been associated with that of Professor Roozeboom, and should have called forth such an elaborate communication from Baron H. von Jüptner, who was indeed the first to introduce, in the Journal of this Institute, the mathematical treatment of the carbon iron solution theory. Baron von Jüptner asks for fuller information with respect to the Le Chatelier formulæ given in my paper, in which, on account of the complicated nature of the problem, I had merely stated the results. A sufficiently full account, with references to Le Chatelier's work, will be found * in a paper by Sir William Roberts-Austen and myself, " La Constitution des Alliages Métalliques," presented to the International Physical Congress which met recently in Paris. It is assumed by Baron von Jüptner that the curve AB is composed of two straight lines, and he quotes both Professor Roozeboom and Sir William Roberts-Austen in support of this view. It should be borne in mind that only one set of experiments, those of Roberts-Austen, have been made, upon which Professor Roozeboom and others have all based their theoretical work. These experiments are very difficult to perform, and it is impossible to avoid some experimental errors. My own view has been that the data at present available are scarcely sufficient to decide whether the curve AB really consists of a single curve or of two almost straight lines. In view of the importance of the subject, it would be advisable to repeat them with every possible precaution before proceeding further with the theories which must rest upon them.

It is also stated by Baron von Jüptner, unless I misunderstand his meaning, that my arrangement of the lines $\alpha S'$ and SE would indicate (at temperatures between say 800° and 1000°) that cementite would be more stable than free carbon. To my mind the arrangement I have adopted indicates that free carbon would be more stable than cementite, for the following reason:—Imagine at say 900° some steel containing an excess of carbon in the form of free cementite. The iron would contain about 1·1 per cent. of dissolved carbon, as indicated by the

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* *Rapport présenté au Congrès International de Physique réuni à Paris en* 1900, pp. 22-28.

line SE, and there would be a quantity of free cementite. If now the line *a*S′, which shows the solubility of free carbon in iron, lie to the *left* of SE, as I have drawn it, it is evident that the iron containing 1·1 per cent. of dissolved carbon would be supersaturated with respect to free or temper carbon, and that if sufficient time were allowed, and the conditions were otherwise suitable, free carbon would separate from the iron until the latter only contained about 0·5 per cent. of carbon as indicated by the line *a*S′. The iron would then be in a condition to dissolve some of the free cementite, and these processes would continue until the whole of the free cementite had been replaced by free carbon.

This argument appears to me to show that any temperature at which free carbon is more stable than free cementite, the curve *a*S′, denoting the solubility of free carbon, must lie to the left of the curve SE, which denotes the solubility of cementite.

I should have been glad if Baron von Jüptner had pointed out the flaw in this argument, as he appears to arrive at a different conclusion. Perhaps, however, the wording in my paper was not quite clear, and has thus led to misunderstanding.

The remainder of Baron von Jüptner's communication deals mainly with the paper of Professor Roozeboom, but I am glad to notice the importance which he attaches to the influence of the rate of the cooling which necessarily follows all experiments at high temperatures, and the advisability of making a number of fresh experiments under conditions indicated by the theoretical work.

VISITS AND EXCURSIONS AT THE PARIS MEETING.

In connection with the Paris Meeting an influential Local Reception Committee was formed to make arrangements for receiving the Institute. The President of the Committee was Mr. Robert de Wendel, President of the Comité des Forges, and the other members were:—Baron de Nervo, Vice-President of the Comité des Forges; Mr. Eugène Schneider (of Le Creusot), Vice-President of the Comité des Forges; Baron de Vaufreland, Treasurer of the Comité des Forges; Mr. A. de Montgolfier, Director-General of the St. Chamond Company, Member of Council of the Comité des Forges; Mr. Henri de Wendel (Bessemer Gold Medallist); Mr. Haton de la Goupillière, Membre de l'Institut, President of the International Congress of Mining and Metallurgy; Mr. Adolphe Carnot, President of the Société d'Encouragement pour l'Industrie Nationale; and Mr. Gustave Canet, President of the Société des Ingénieurs Civils de France.

It would be very difficult adequately to express the visitors' appreciation of the excellence of the arrangements made by this Committee, or of the hearty manner in which the members were welcomed during the meeting. Mr. Henri Vaslin, who was good enough to act as Local Honorary Secretary during the meeting, will long be remembered for his extreme courtesy, tact, and organising skill. Mr. Henry Chapman, who undertook the arduous duties of Local Honorary Secretary at the previous Paris meetings in 1878 and 1889, again contributed largely to the success of the meeting by placing his Paris offices at the disposal of the Institute.

The proceedings on September 18 began with great punctuality, and the Council had every reason to be satisfied with the support they received from members, as evinced by the large attendance, the spacious hall of the Société d'Encouragement being filled to overflowing a few minutes after 9.30 A.M. On the second day, also, the business of the Institute meeting was begun in good time, the attendance being again large.

VISIT TO THE PARIS EXHIBITION.

During the afternoons of September 18 and 19 the Exhibition was visited, where groups were formed under the guidance of experts for the purpose of examining the various sections of metallurgy, mining, and machinery.

The Paris Exhibition of 1900 covered a larger area than any Exhibition previously held in that city. The site occupied comprised the Champ de Mars, the Esplanade des Invalides, the Trocadèro Gardens, a portion of the Champs Elysées, the quays on both sides of the Seine, between the Alexander III. Bridge and the Pont d'Jena, and the Park at Vincennes.

The total superficial area was as follows:—

Champ de Mars	124	acres
Esplanade des Invalides	30	,,
Trocadèro Gardens	40	,,
Champs Elysées	37	,,
Quays on the left bank of the Seine	23	,,
Quays on the right bank of the Seine	23	,,
Park at Vincennes	272	,,
Total	549	,,

The superficial area occupied by buildings and covered in is believed to have amounted to 4,865,328 square feet, distributed as follows:—

French Sections	2,691,000	square feet
Foreign Sections	1,829,880	,,
Park at Vincennes	344,448	,,
	4,865,328	

The strip of land on each side of the Seine devoted to the Exhibition extended for a distance of $1\frac{1}{3}$ mile. About one hundred French and seventy-five foreign pavilions and detached buildings were erected in the grounds, without counting the thirty-six official pavilions of nations participating in the Exhibition; these official pavilions were placed in a double row along the Quai d'Orsay. There are two methods of classifying exhibits to show together on the same site—namely, (1) all products of a country, district, or region, whatever their nature; (2) all products of a similar nature, whatever their origin. From an educational point of view the second method, which is the one that was adopted, is preferable, as it enables both student and expert to appreciate the comparative merits of exhibits when industries of a similar nature are shown side by side. Moreover, the tendency of industries to specialisation renders the adoption of the second method of classification more and more imperative. The classification adopted comprised eighteen groups, subdivided into 121 classes. Mining and Metallurgy formed Group XI., and was divided into Class 63, mining; Class 64, metallurgy; and Class 65, metal-working. Educational, Agricultural, Industrial, and Engineering exhibits were shown in the buildings on the Champ de Mars; Decoration and Furniture in the buildings on the Esplanade des Invalides; Colonial exhibits in special buildings in the Trocadèro Gardens; whilst some branches of Sport and Engineering were shown at Vincennes. Special pavilions had been erected on the river quays for Horticulture, Forestry and Sport, Social Science, Army and Navy and Mercantile Marine, whilst the Fine Arts are placed in permanent palaces erected in the Champs Elysées. The President of the British Royal Commission was H.R.H. the Prince of Wales, K.G. (Honorary Member of the Iron and Steel Institute), and the Secretary was Colonel H. Jekyll, C.M.G. Among the Royal Commissioners were the following members of the Iron and Steel Institute:—The Duke of Devonshire, K.G.; Sir James Kitson, Bart., M.P. (Past-President); Sir E. H. Carbutt, Bart. (Member of Council); Sir F. A. Abel, Bart., K.C.B. (Past-President); Mr. E. Windsor Richards (Past-President); and Mr. S. E. Howell. Among the British jurors appointed to the International Jury were the following members of the Institute:—Class 20, engines, Mr. G. Cawley; Class 21, general machinery, Mr. W. H. Massey; Class 22, machine tools, Sir W. T. Lewis, Bart. (Member of Council); Class 64, metallurgy, Sir William Roberts-Austen, K.C.B. (President); Class 65, metal-working, Mr. Bennett H. Brough (Secretary). The Iron and Steel Institute exhibit in the gallery of Class 64 consisted of the historical collection of original specimens of Bessemer steel, dating back to June 1856, presented by the late Sir Henry Bessemer to the Iron and Steel Institute.

VISIT TO THE LE CREUSOT PAVILION.

The visit of the Institute to Paris could not have been complete without an inspection of the Le Creusot Pavilion, and the invitation of Mr. Eugène Schneider to a reception in this building (on Tuesday afternoon, September 18) was therefore exceedingly welcome, and was very generally taken advantage of, both by the members themselves and the ladies accompanying them. A number of engineers belonging to the works acted as guides. Several of them spoke English fluently, and this rendered the visit all the more instructive to many of the members. On the occasion of the Institute's visit the Pavilion was closed to the general public, and Mr. Eugène Schneider, the head of the firm, assisted by Mr. G. Canet, received the visitors at the entrance.

THE LE CREUSOT PAVILION.

The Le Creusot Pavilion, a huge dome-shaped building, 141 feet in diameter and 130 feet in height, crowned with a campanile 13 feet in diameter, might have been taken for a massive armoured fort with its projecting guns. The roof was constructed of three-hinged trusses of H-section, forming twenty-four ribs, 18 feet apart at their feet and converging to a special spherical bearing in the centre at the top of the dome. The upper part was roofed with wood and plaster painted red, and the lower part was glazed. As the Moulineaux Railway ran through the building, half of the floor space on the side away from the river Seine was raised to a higher level and carried on girders of 56½ feet span resting on walls built outside the walls of the railway cutting and independent of them, so as to carry the weight of the exhibits with safety. On this raised portion were exhibited a large number of different types of guns and mortars, while the lower part of the building contained the engines, locomotives, and electric plant, besides armour plate. The cannon ranged in size from the 24-centimetre gun with its armoured turret, for the Spanish navy, down to the 10-centimetre quick-firing guns and 75-millimetre field-pieces, and even smaller. The breech mechanisms were of numerous types, and in some of them a single movement was all that was required to unlock and throw out the breech block. Hydraulic and electric gearing were both shown in operation for manipulating the guns and their mountings, &c., while the recoil apparatus was of all types, including the latest forms of hydro-pneumatic control.

On the ground floor the Thuile high-speed locomotive occupied a prominent position in the centre. With loads of 180 to 200 tons it is designed to run at 75 miles per hour, with a horse-power of 1800 to 2000, and it will traverse curves of 470 feet radius. It is carried by a four-wheeled bogie in front, four-coupled driving wheels, and a six-wheeled bogie behind. The tender, carrying 7 tons of coal and 7400 gallons of water, is mounted on two bogies. The weights of the empty locomotive and tender unloaded are 75 and 24 tons, and loaded, 83 and 59 tons respectively. To reduce the weight, the boiler plates, rivets, cylinders, &c., were made of nickel steel, with a tensile strength of 31 to 35 tons per square inch, while the connecting rods and cranks were of similar material, with a tensile strength of 38 to 41¼ tons.

The triple expansion engines for the triple screw vessel *Kleber* also formed a noteworthy exhibit. The diameters of the cylinders are 33·8, 49·1, and 76·7 inches, and the common stroke is 31·5 inches. At 150 revolutions each engine develops 5700 horse-power. An electric locomotive was also shown. It is fitted with four electro-motors rated at 200 horse-power, and each driving a separate axle by means of spur gearing. It weighs 50 tons, and has drawn a load of 300 tons up a gradient of 1·1 in a hundred at a speed of 28 miles per hour.

In connection with this visit it may be of interest to refer briefly to the various undertakings controlled by Messrs. Schneider & Co. These include iron ore mines in Spain and at Mazenay, Créot, Change, and St. George d'Hurtières; collieries at Le Creusot, Decize, Montchanin, and Longpendu; firebrick works at Perreuil; blast-furnaces, steelworks, and rolling-mills at Cette and Le Creusot; and various works for the manufacture of bridges and other structural work, war material, electrical work, &c., &c., at Chalon-sur-Saône, Champagne-sur-Seine, Le Creusot, and Havre, in addition to the testing grounds for ordnance, &c., of Le Creusot and Havre.

The first works were started in a modest way at Le Creusot, and in 1836 were acquired by Messrs. Schneider, who foresaw the tremendous development of the iron industry due to the introduction of railways. At the present time there are five blast-furnaces in blast making iron with coke produced from a mixture of anthracite and caking coal in 200 ovens. For the manufacture of steel there are four 35 open-hearth furnaces and two basic converters. A large casting pit, capable of accommodating castings up to 120 tons in weight, is commanded by a

150-ton electric crane, and a 10,000 ton press is available for compressing liquid ingots, the only plant of its kind in France. Rotary puddling furnaces are used for the preparation of exceptionally pure material used in the manufacture of guns and armour plate. In the forge there are seven steam-hammers, ranging from 20 to 100 tons, each served by its own furnaces and cranes and four forging presses rated at 1500, 2000, 3000, and 6000 tons. The 100-ton hammer is really to be considered of 120 tons, and it is served by four furnaces and four cranes of 100 to 160 tons. It is used for forging armour plate up to 24 inches in thickness and 65 tons in weight. For tempering gun tubes, a well 65½ feet deep is provided, besides all appliances for treating armour with oil or water tempering processes. Three overhead travellers of 100, 80, and 40 tons are used for handling the work in this department. A recently built tire mill is capable of turning out 12,000 to 15,000 tons of tires of all sizes annually.

In the rolling-mills there are some 140 engines with a total of 12,000 horse-power, and from 120,000 to 140,000 tons of finished products are made yearly, ranging from merchant iron ¼ inch in diameter to armour plates of 40 tons weight. For merchant and section iron and steel there are twelve three-high mills and four trains for plates and sheets, besides a special mill for fine sheets. The present armour plate mill is to be supplemented by a new one capable of handling work up to 60 tons in weight.

Of the extent of the various manufactories for finished articles it would be hopeless to give any idea within the limits of a short note, but the various appliances shown at the Exhibition and referred to above will indicate some of the capabilities of the Company.

THE SOIRÉE MUSICALE.

The *Soirée Musicale* given on Tuesday evening, September 18, by the Comité des Forges de France was organised in a masterly way, and carried out royally. From first to last it was a most interesting and successful function, greatly owing to the way in which every detail had been studied. The Local Reception Committee, headed by its president, Mr. Robert de Wendel, were evidently sincerely pleased to have the opportunity of entertaining the members and the ladies accompanying them. One may also safely say that the ladies and members enjoyed quite as much the pleasure of being the guests of the Comité. The programme had been drawn up with a skill that showed a master-hand. The fact that of the eight numbers six were performed by members of the Paris Grand Opera is a sufficient proof of their excellence.

VISIT TO THE ROYAL PAVILION.

On the afternoon of September 19 the members and the ladies accompanying them were hospitably entertained in the Exhibition at the British Royal Pavilion by the Commissioner-General and Mrs. Jekyll, and carried away with them most pleasant recollections of a delightful social function.

The Royal Pavilion, built by the British Royal Commission, stood between the Belgian and Hungarian Pavilions, midway between the two bridges, and exactly opposite the Palace of Horticulture and Arboriculture on the other side of the Seine. The building was designed to represent an old English manor-house, and was furnished and fitted with the modern appliances of a country-house. The north side of the Pavilion was an adaptation of the south façade of the Hall at Bradford-on-Avon, one of the finest existing specimens of Jacobean architecture, built at the beginning of the seventeenth century. The rooms were so arranged as to enable the public to circulate through the house, and make their exit by a second door. The main entrance was by a porch on the south side; this led into the hall, which contained a set of tapestry panels designed by the late Sir E. Burne-Jones, executed by Morris & Co. On the right of the hall was a small room fitted and decorated by the Corporation of the City of Bath. Traversing a short corridor, visitors then passed through the dining and reception rooms on the ground floor, ascended the great staircase, and traversed the long gallery. This gallery was an adaptation of the cartoon gallery at Knole House, Sevenoaks. A loan collection of the finest examples of the British School of painting, chiefly of the eighteenth and early nineteenth centuries, was shown here and in the rooms on the ground floor. Leaving the gallery, visitors entered the china room, which contained specimens of English ceramic ware, and then passing a series of bedrooms, arrived at the second staircase, from which the door of exit was reached. The framework of the building, constructed entirely of steel, of which about 310 tons had been used, was designed by Sir Benjamin Baker, Member of the Iron and Steel Institute. The floors are of concrete, and the outer walls were made of plaster on corrugated steel and expanded metal.

BANQUET AT THE HOTEL CONTINENTAL.

On the evening of September 19 the Institute entertained the Reception Committee at a banquet at the Hôtel Continental. Sir William Roberts-Austen, K.C.B., President of the Institute, presided, and 250 members and their friends were present. The guests who accepted the invitation of the Institute were Messrs. Robert de Wendel, President of the Comité des Forges; E. Schneider, Vice-President; Baron de Vaufreland, Treasurer; H. Pinget, Secretary; C. Boutmy, Lesaffre, G. Baty, and A. Sepulchre, Members of Council; A. Gigot, La Ferté, and Paraf, Honorary Members of the Comité des Forges; G. Canet, President of the Société des Ingénieurs Civils; the President of the Municipal Council of Paris; A. Lodin, P. Arbel, Brustlein, A. Chappée, and F. Raty, members of the metallurgical jury at the Exhibition; Vesier, President of the Compagnie Française des Métaux; Demenge, managing director of the same company; Gény, managing director of the Le Creusot Works; Buquet, director of the Ecole Centrale; Sauvage, chief engineer of the Western Railway Company; Baudry, chief engineer of the Lyons Railway Company, and Solacroup, chief engineer of the Orleans Railway Company; Bonnassies, of the St. Chamond Company; and François de Wendel, Dutreux, Ast, and Charvet, engineers, who kindly acted as guides at the Exhibition. The British guests included Colonel Jekyll, the British Commissioner at the Exhibition, and General Festing, C.B.

The PRESIDENT, in proposing "Her Majesty the Queen," said: "I will only add, for I wish to be very brief to-night, that tenacity and endurance, attributes of steel, are precisely the qualities we should wish to possess were it necessary for us to express our devotion to Her Majesty. Gentlemen, I give you the health of the Queen—God bless her."

The PRESIDENT again rose and said: "We have come to France to express our homage to this great country on the occasion of the splendid International Exhibition which so nobly crowns the century. France has always been a paradise. I love her with all my heart. I am sure you will drink with every sign of enthusiasm to the President of the French Republic."

The PRESIDENT again rose and proposed a toast of cordial fraternity. He said: "I rise to propose 'Our Guests,' and to this toast I will add the name of the President of the Comité des Forges de France. There are one or two others I would specially mention, We have here not only the leading members of the Comité des Forges and the Secretary, Mr. Pinget, but we have the members of Class 64, the jury which was specially charged with the metallurgical work, and we have the representatives of the great railway companies. We have Mr. Vaslin, who has done so much for us, as you all know, in making our meeting go smoothly and preparing the way for us in every possible way. We have Mr. Schneider, who received us so magnificently in that splendid pavilion to which we were all invited yesterday and received so hospitably. We have also Mr. Canet, who represents the Civil Engineers of France; and Colonel Jekyll, who has looked after our British interests so admirably in connection with the great Exhibition; and we have also the gentleman whose name I am about to couple with the toast. It is very difficult for me to express the gratitude which is in all your hearts. We shall go away from France with precious memories which will remain with us for the rest of our lives. Last night we heard quoted a great French writer, Madame de Staël, who has told us that things as regards ordinary life fade gradually as our meeting is fading away, but it is not so with the life of the century. Its garland is of steel, and its flowers and leaves have been garnered and cultivated by the ironmasters of both our nations. We hand it on to future generations untarnished. I couple with the toast the name of Mr. Robert de Wendel, the President of the Comité des Forges de France, to whom we all owe so much."

Mr. ROBERT DE WENDEL, who was received with cheers, said: "Messieurs, je ne puis que remercier votre Président des paroles si aimables qu'il vient de prononcer à l'égard du Comité de réception. Je puis vous dire que l'accueil que nous vous avons fait, nous l'avons fait de tout cœur, et vous le trouverez tout naturel si vous pensez à l'accueil que vous nous faites chaque fois que l'un de nous va en Angleterre. Vous la trouverez aussi tout naturel en songeant que nous appartenons tous à la grande famille des métallurgistes. Hier, Messieurs, j'avais l'honneur de vous rappeler les liens qui unissent beaucoup d'entre nous à votre industrie, et je suis sûr d'être l'interprète de tous mes confrères en exprimant le désir que ces liens deviennent de jour en jour plus intimes et de jour en jour plus affectueux."

Mr. G. CANET (the President of the Society of Civil Engineers of France) said: "It is a great pleasure to me to see my English friends. You will excuse me addressing you in English to propose a toast that you will receive, I have no doubt, with enthusiasm. To speak your language will put me in mind of the happy years I spent in your country, where I had the good fortune to learn my trade in a technical point of view, and also the English ways of doing business. All this has been so useful to me in life that I shall never forget it. In June last I had the great honour and pleasure to receive, as President of the Society of Civil Engineers of France, delegates of your Institute, at the head of whom was your honourable President, Sir William Roberts-Austen, and it is a great pleasure for me to be received in my own country by your President and such a large number of your members. We civil engineers of France follow with keenness your numerous and remarkable works of research. It is you who in a sense give us our daily bread in the shape of good steel and iron, for without these the industry of life is bound to decay. Your discoveries are the basis of all engineering works and form, and it is therefore with a heartfelt pleasure that we welcome you to Paris, the eminent representatives of the first Institution, and I invite you all to drink the health of your honourable and learned President, Sir William Roberts-Austen."

The PRESIDENT, in reply, said: "What am I to say? I can only say that I thank you from the very depth of my heart, and that the one event of my life to remember with pride is that you came in such numbers to France, the land we English love so much. I will say nothing more except to tell you how glad we are that Mr. Canet learned anything from us. How much we have learnt from France—how much I owe to her, will be revealed by the address which I did not read the other day. I have nothing to add from a full heart except my most grateful thanks."

VISIT TO THE EXHIBITION AT VINCENNES.

On September 20 the members visited the portion of the Exhibition at Vincennes. The "Annexe" of the Exhibition was situated to the east of Paris in the Park of Vincennes. It included the Daumesnil lake, and was bounded by the fortifications between the Charenton Gate and Picpus Gate, by the Avenue Daumesnil between the Picpus Gate and the road to Saint-Mandé, and by the road to Gravelle. It was reached (1) by the Vincennes Railway from the Place de la Bastille; (2) by the Ceinture Railway to Rue Claude Decan Station; (3) by the steamers of the Compagnie des Bateaux-Parisiens to the Pont de Charenton; (4) by the Louvre-Charenton Tramway to the Pont de Charenton; and (5) by Electric Tramway from the Bastille to Charenton. The objects exhibited at Vincennes comprised locomotives, machine tools, motor-cars, bicycles, and a typical series of workmen's dwellings as erected in France, England, Germany, Austria, Belgium, and Switzerland.

RECEPTION AT THE HÔTEL DE VILLE.

In the afternoon the members were received at the Hôtel de Ville by the President of the Municipal Council of Paris. The reception was largely attended. The Hôtel de Ville is a magnificent block of buildings, in the style of the French Renaissance, and its artistic and decorative treasures were greatly admired. The President of the Municipal Council, Mr. Grébauval, welcomed the President and members of the Institute in a stirring and eloquent address, in the course of which he dwelt upon the part played by metallurgy in the progress of civilisation during the past century. He showed a thorough grasp of the subject, as well as of the constitution and history of the Institute. At the close of the formal reception the President of the Council, after offering refreshments to his guests, conducted the party over the building, explaining the numerous objects of interest. The reception lasted about an hour and a half, and was thoroughly enjoyed by the visitors.

RECEPTION BY THE MINISTER OF PUBLIC WORKS.

The members of the Institute were invited by the Minister of Public Works to an evening reception on September 21. Unfortunately this clashed with the official reception of the 22,000 Mayors invited to Paris by the French Government, and it became necessary to postpone the Minister's *soirée* until Monday, September 24. Most of the members had then left Paris. The President and Lady Roberts-Austen remained to enjoy the Minister's hospitality, as also did Sir David Dale, Mr. and Mrs. Hadfield, Mr. and Mrs. Bennett Brough, and several other members and the ladies accompanying them.

THE PRESIDENT'S DINNER.

On September 17 the President entertained the Council at dinner at the Pavilion Paillard in the Champs Elysées. The party included Sir Lowthian Bell, Bart., Mr. E. P. Martin, Mr. W. Whitwell, Mr. G. J. Snelus, Mr. R. A. Hadfield, Mr. W. Beardmore, Mr. J. E. Stead, Mr. A. Greiner, Mr. F. W. Webb, Mr. W. Evans, Mr. Henri Vaslin, Mr. Bennett H. Brough, Mr. Baily, Mr. Stanley, and Sir Thomas Wrightson, Bart., M.P.

THE EXCURSION TO LORRAINE.*

The ironworks at Hayange, Moyeuvre, and Stiring Wendel, belonging to Les Petits Fils de François de Wendel et Cie., were visited in 1878 by a group of members of the Iron and Steel Institute. Since that date the introduction of the basic process has led to the closing of the Stiring Wendel Works, of which the speciality was the manufacture of iron rails, and three basic steelworks have been established, one at Hayange (Germany), the second at Moyeuvre (Germany), and the third at Joeuf (France). These works are situated at the northern end of the oolitic iron ore region in the neighbourhood of Longwy and Thionville, and all the iron is made from the minette ores of the locality, but the coke is imported from Westphalia. During the year 1899-1900 these works produced—

	Hayange and Moyeuvre. Tons.	Joeuf. Tons.
Pig iron	477,600	193,000
Rolled products	298,000	125,000

Twenty members of the Institute, who had left Paris overnight and arrived at Metz early in the morning of Friday, September 21, were met at Ueckingen by Mr. Henri de Wendel and his sons, and conveyed by one of the works trains to the steelworks at Hayange, and then to the blast-furnaces and steelworks at Joeuf. After an adjournment to lunch at the adjacent chateau, the train was again taken on to the rolling-mill plant at Jamailles, and finally returned to Metz in the evening. During the adjournment, in reply to some remarks by Mr. E. P. Martin, Past-President, Mr. Henri de Wendel gave some interesting retrospective particulars of the works as follows:—

"Gentlemen, in the year 1879, on the occasion of the Paris Exhibition, I had the honour of entertaining at Hayange a group of members of the Iron and Steel Institute. It is a great satisfaction to the members of our firm and our collaborators to see twenty years later a new party of the Institute coming here again. This circumstance leads us to think that the impression of your previous visit had not left a bad remembrance on your minds. I am more anxious, however, about the present visit. When you came in 1879 our plant was a new one. You saw at work fifty puddling-furnaces fitted with mechanical puddlers, with a production of 400 tons of puddled bars in twenty-four hours. The rolling-mill department was fitted with the reversing engines then recently introduced by your celebrated Ramsbottom. In fact, the plant was quite new, but its life, if happy, was short. I believe, gentlemen, that in 1879 you came here to render the funeral duties to puddled iron. In fact, during the following year the process of our very lamented colleague and friend Thomas came to overturn all that we had previously done. We were obliged to build immediately the steelworks at Hayange and Joeuf, from which you will conclude that the steelworks are twenty years old, and rather antiquated, and do not offer anything new to members who are specially connected with the Thomas process. This morning, however, you have inspected at Hayange a rolling-mill department fitted with more modern appliances, allowing rails, sleepers, and every section of structural iron to be rolled without the loss of time required for changing rolls or requiring a diminution in the producing power of the steelworks. I hope that this part of your visit may have some interest for you, and I conclude by expressing the wish that the actual arrival of the members of the Iron and Steel Institute will not at the present time announce the ending of the basic process in the manner that your former visit announced the death of puddled iron. I express my most fervent wishes for the welfare of the Institute, and my most hearty thanks to the members who have honoured us with their kind visit and have undertaken for it so long a journey."

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* Report kindly furnished by Mr. H. G. Graves, Assoc. R.S.M.

THE WORKS AT HAYANGE.

At Hayange there is a large blast-furnace plant, but owing to lack of time only the steelworks were visited. Steel is made in six basic-lined converters grouped in pairs in one line, each pair having a centre ladle crane and a number of common ingot stripping cranes placed between and in front of the semicircular casting-pits. The converters are placed at one end of the fine new building, which covers about 14 acres, and contains all the rolling-mills, cooling beds, and storage room for the rolled products. The ground is entirely covered by ridge-and-furrow roofing with light trussed girder roofs supported on lattice-work pillars, and forming nineteen parallel bays of six and eight metres span. Each bay is commanded by an overhead traveller electrically driven. The slings or dogs for picking up the material run on a slotted girder, which is raised or lowered from the drums on the crane, so that any size of work can readily be tackled and transferred from one side of the bay to the other. The converters take charges of 13 tons of metal from a mixer supplied from the blast-furnaces, and the steel is cast into four 3-ton ingots, which are sent through gas-fired soaking pits to the cogging-mill, driven by a twin compound engine built in 1895. The sheared ingots are transferred by an overhead traveller to a large central reheating furnace, into which they are pulled by a chain led round a guide-pulley to a vertically-acting hydraulic ram. From the opposite side of the furnace they are discharged on to a line of live rollers, which lead them to the finishing-mill. Beyond this are extensive cooling-beds, with rope-haulage appliances. The same building also contains the two-high reversing bar-mill, driven by a three-cylinder engine. On one side is a long inclined shoot, and on the other side live rollers followed by an electrically-driven shearing-machine. The live rollers here are driven in a most ingenious manner. The axles of the rollers run between horn-plates, so as to have a slight vertical play, and the rollers themselves lie on two endless running ropes, so as to get a frictional drive. The mills are of the ordinary two high-class mill reversing engines of a type familiar in this country, with hydraulic side traversing gear and steam-driven live-roller trains, and as such calling for no special remark. What is, however, of interest is the liberal manner in which the plant has been designed, the mills and their engines being so arranged as to meet sudden demands for very rare sections without having to stop for changing rolls, *i.e.* separate mills are kept ready for each class of work, so that the stuff can be transferred from one to the other as required without delay. An example of this flexibility in working was given to the visitors, who, during the short period of their visit, saw joists about 15 inches deep, wire billets, and medium-sized angle bars rolled successively by the same set of men in the different works.

THE WORKS AT JOEUF.

At Joeuf there are six blast-furnaces, of which five were in blast and one under repair. Each makes 100 to 120 tons daily, being equipped with four tall and narrow Cowper stoves each, and supplied with blast at 200 millimetres of mercury pressure. No water plates are built into the furnaces, which are, however, cooled externally by flowing water in large quantities. The average fuel consumption is 23 cwt. per ton of iron. The age of these furnaces differs considerably, and one has been in blast for seventeen years. The pig-beds are

PLATE XXIII.

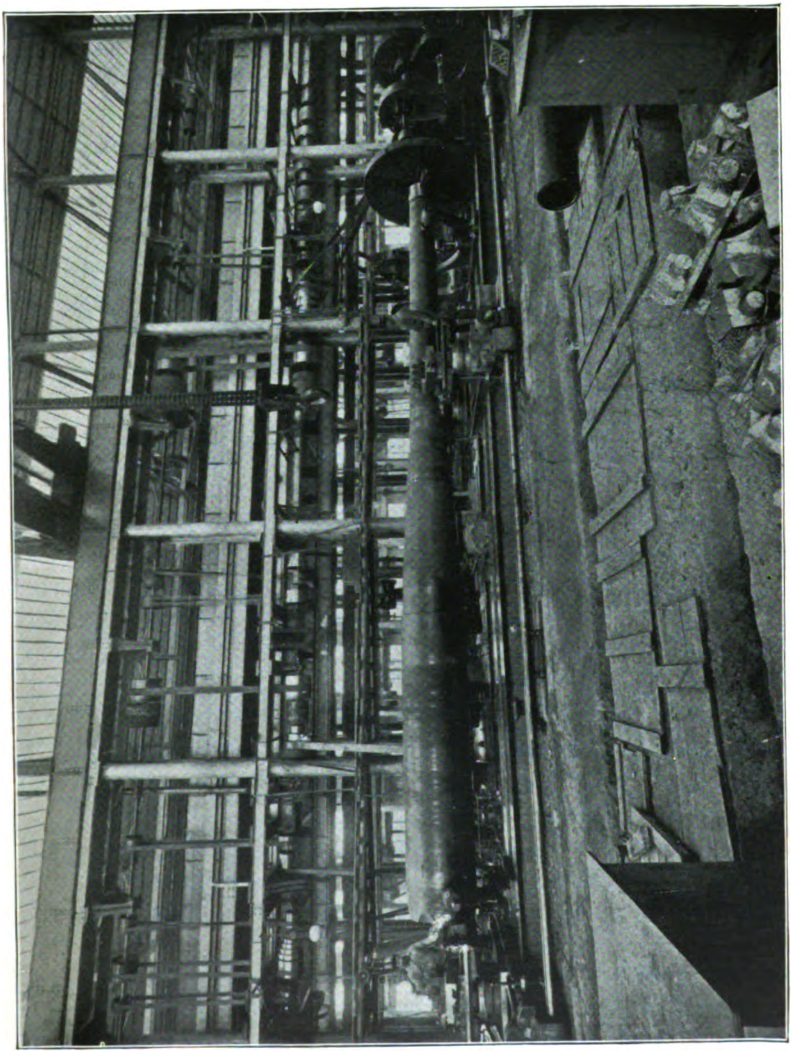


Fig 1.—12-Inch Gun in Shop B.

PLATE XXIV.

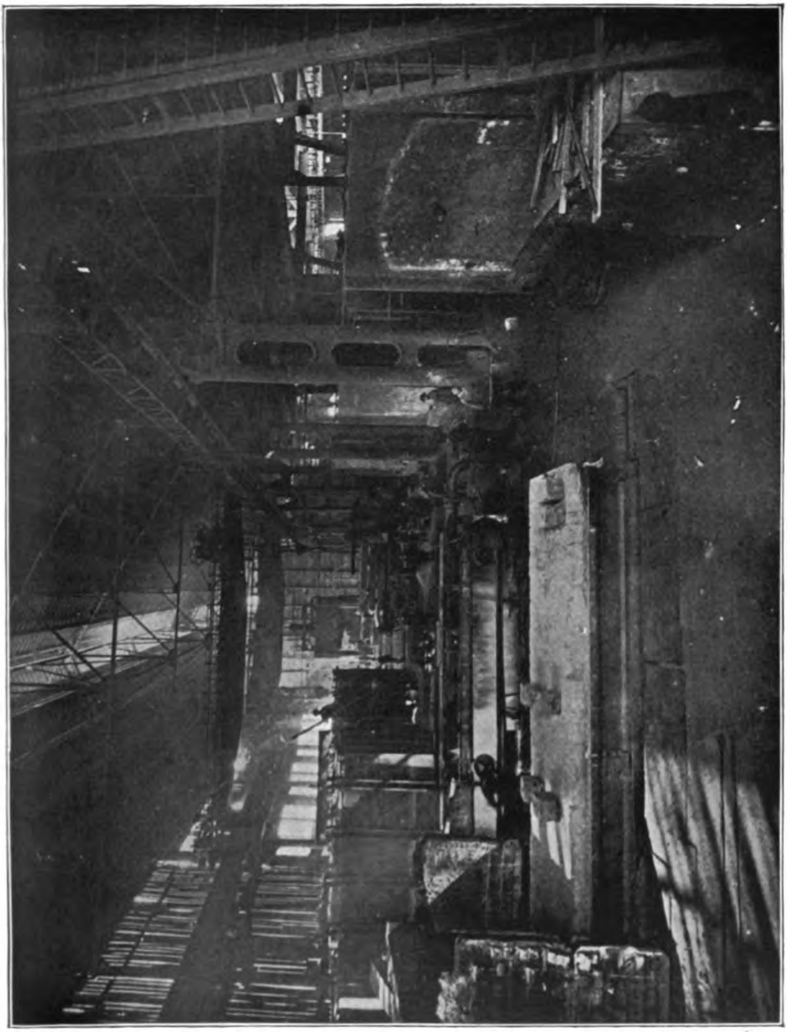
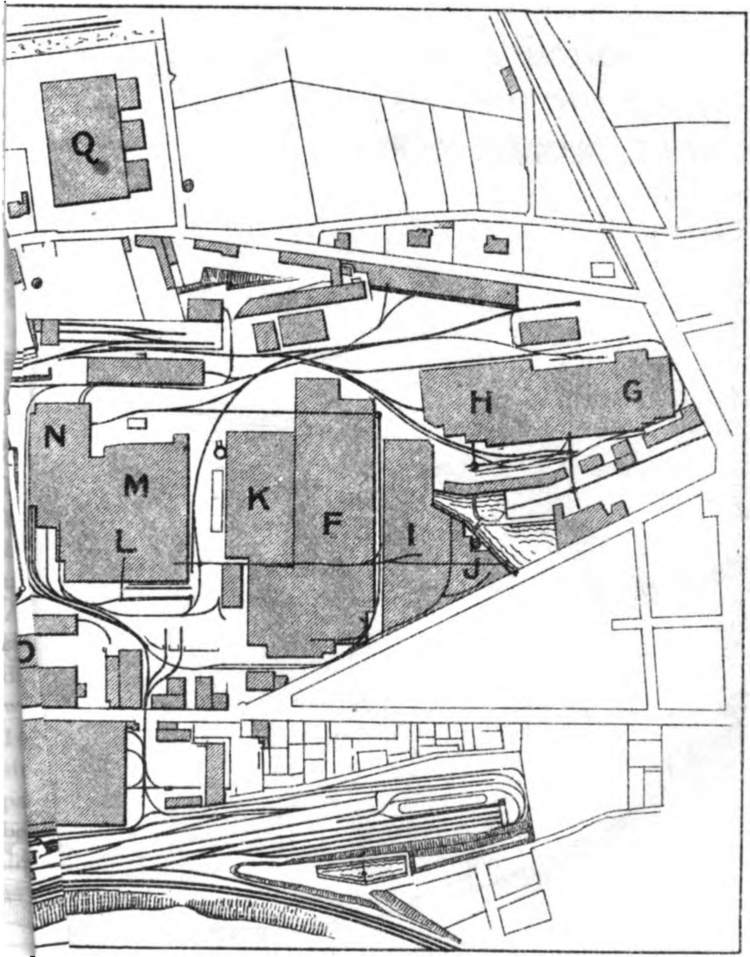


Fig. 2.—Armour Plate; Cementation, Spray Tempering, and Shaping, Shop I.

PLATE XXV.



Ballantyne, Hanson & Cº Edinburgh & London.

very small in capacity, as most of the iron is taken to the converters direct, but a little is cast into chill-moulds. Adjacent to the furnaces is a very fine row of eight blowing-engines, of the vertical inverted type, of various dates, including one built in 1894, three in 1881, one in 1884—all by Schneider; one by De Wendel in 1884, one in 1887 by the Bayenthal Company, Cologne, and one by Hargreaves, of Bolton, in 1884. The aggregate power is about 2500 horse-power. In the same building, but in a separate room, is placed a remarkably fine twin compound vertical engine of 1500 horse-power supplying blast to the converters at 30 lb. pressure, and provision has been made for duplicating it.

As at Hayange, there are six similarly arranged basic converters in a line. Some distance in front of them, and flanked by a couple of reheating furnaces of a modified Bicheroux type with closed ash-pits blown by 4-foot fans, is a large cogging-mill, beyond which again is a billet-mill and its appurtenances. The rollers discharge the sheared billets on to an inclined belt-conveyer, which loads them direct into railway trucks. 70-lb. rails cut to 18 metre lengths were being made. Farther on in the same building is the wire-rod rolling-plant, which is of the Belgian looping or continuous type, with the stands all in one line, and repeaters or guides on the rear side to bring the issuing end back to the next pass, this being done on the front side of the mill by hand. Only short loops are made, as the successive rolls are speeded up, so that the increase of speed nearly counterbalances the extension. A small three-high mill in front gives the preliminary reduction, and three vertical automatic reels coil the finished wire-rod. The mill is driven by a fine pair of tandem compound condensing engines, supplied with steam from boilers of the locomotive type, developing 1200 to 1400 horse-power. At the time of the visit two rods were being rolled simultaneously, but as many as six may be in the mill at once, the passes, of which there were seven, excluding those in the advance mill, being repeated in each stand. The best day's work on this mill was done on February 20 of this year in two twelve-hour shifts, and was as follows:—

	First Shift.	Second Shift.
	Kilos.	Kilos.
Consumption of ingots	46,700	44,800
Wire-rod made (first quality)	42,200	40,280
Do. (second quality)	200	230
Waste and spoilt	908	1,000

The Rolling-Mills at Jamailles.

At the mills at Jamailles nearly a hundred thousand tons of section and merchant steel of all kinds are rolled annually; and the works are crammed to the utmost with long trains of three-high rolls all in full activity. Small mechanically operated lifting-tables were in general use at the rear side of the mills, but for very light sections all the manipulation is done by hand. As at the other works, nearly all the supplementary machinery is driven by electromotors with continuous currents at 250 volts.

Excursion to St. Chamond.*

The St. Chamond Works is one of the properties of the Compagnie des Forges et Aciéries de la Marine et des Chemins de Fer, a company which originated in 1837, and since then has passed through various stages of progress, until at the present time it has a capital of twenty million francs, and is possessed of the following properties in addition to St. Chamond:—Iron and steel works at Assailly (Loire), at Rive-de-Gier (Loire), at Givors (Rhone), and at Boucau (Basses-Pyrenées); collieries at Unieux and Fraisse (Loire); iron mines at Ougney (Jura), at Saint Léon (Sardinia), and at Lamiari and Montoya (Spain); forests in Corsica, and important concessions for iron ore at Chevillon (Meurthe-et-Moselle). In ordinary times from 8000 to 10,000 work-people are employed by the Company, and large sums of money are annually expended in the improvement and development of the equipment and in erecting new workshops, at the present time under the direction of Mr. J. Girard and Mr. Leroy. Most diversified, too, are the products:—Sections, rails, metal sleepers, and small materials for the permanent way at Boncau, visited by some members of the Institute in 1896. Forged locomotive and waggon wheels of all patterns, parts of marine machinery, stern-posts, rudders, &c. at Rive-de-Gier. Railway springs, specially light wheels, and delicate thin steel sheets at Assailly. Field, siege, and battery artillery, naval guns, cannon of all calibres, ammunition and projectiles, armoured turrets and towers for coast defence, for war-ships and for land forts, armour-plates, propeller and crank shafts, rails, tires, sections, forgings, steel axles, iron and steel frames, and all kinds of plates and sheets for railway rolling stock and general purposes, is the long list of things manufactured at

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* Report kindly furnished by Mr. D. A. Louis, F.I.C.

St. Chamond. These works are situated in the town of that name, which is a few miles north-east of St. Etienne, on the road between that town and Lyons, and is reached from Paris by train to either of the latter towns and thence on to St. Chamond.

The district in which St. Chamond is located is of considerable industrial importance, with an annual output of manufactured produce valued at from £10,000,000 to £12,000,000. It, moreover, is rich in historical associations connected with the iron and steel industry, as, in fact, Mr. A. de Montgolfier pointed out in an interesting speech delivered after the luncheon at which he entertained the visitors on the present occasion at his residence. He recalled the fact that the first public railway in France was from St. Etienne to St. Chamond, and had been traversed by those present that day. On the way, too, they had passed through a tunnel under the celebrated Terrenoire Works, where the first blast-furnace in France was erected with blowing engines by Watt, where, too, the first puddling furnaces in France were established with puddlers brought from England, who settled down in the neighbourhood and founded generations of puddlers. Then the secret of working crucible steel was introduced into France by Englishmen at the Assailly Works, founded by them. Furthermore, the first weldless tires were made and the first armour-plates were manufactured at St. Chamond, the former in 1849, the latter in 1854; moreover, they retained the monopoly of these manufactures for years, and the original mills are working still, and, in fact, were seen working during the visit. In early days St. Chamond gained a high reputation, which it has most scrupulously maintained ever since. The control of the selection and blending of the raw materials by analysis and tests, the testing and analysing of the articles manufactured at every stage of their progress through the works, is most strictly carried out under the direction of Mr. de Nolly and Mr. Heurteloup, and quite an array of tools are constantly employed at this work. Moreover, to ensure excellence, the most approved practice and plant, whether of their own or foreign origin, is readily adopted. Thus, besides facts already mentioned, St. Chamond was the first in France to employ the Bessemer as well as the open-hearth process. Evidence of this eagerness for excellence was visible throughout the establishment.

The works were visited in 1889 by a party of members of the Institute, who left Paris at 8.5 P.M. On the present occasion the party were to leave at the same time, but owing to difficulties with the sleeping-car, the time was altered almost at the last moment to 7·20. The announcement of the change was circulated as freely and quickly as possible, with the result that most of the participants dined together at the Lyons Station in Paris previous to departure, and were comfortably and agreeably installed in the sleeping-car; two members, however, who had not heard of the change of time, followed by the original train, but arrived at St. Etienne at the same time as the others. After breakfast at St. Etienne the party proceeded by train to St. Chamond, where they were met at the station by Mr. A. de Montgolfier, the managing director, amongst others, and after a few words of welcome, were taken in conveyances to the works. In the office Mr. A. de Montgolfier introduced Mr. Henry de Montgolfier, director of the works and chief engineer, Mr. Joseph de Montgolfier, engineer at Paris, and other gentlemen whose names will be mentioned in connection with their departments, where they officiated as guides. Mr. A. de Montgolfier then explained the day's programme, which, under the admirable leadership of Mr. Henry de Montgolfier, was punctiliously carried through, and was rendered interesting and valuable by the readiness with which he himself and the various others who accompanied were at all times ready to furnish any information required. Another noticeable and agreeable feature of the visit was the absolute openness of everything; there was no door marked private, and no forbidden entrance or barred passage, but the "open door" policy was most freely practised.

The course followed on the present occasion is indicated by the order of the lettering on the plan, Plate XXV., and a start was made with a hasty walk through yards and passages, but not too hasty to prevent the observation of the good order which prevailed everywhere, even to the scrap heaps—an orderliness, moreover, that was not restricted to the exterior, but was to be remarked throughout the various shops, both great and small, subsequently visited; and what perhaps was still more remarkable was the smoothness with which the various big operations witnessed were conducted, a few simple signals sufficed in all cases for directing manipulation without bustle or confusion. The shop A was the first visited; it is the great forging shop, a lofty, imposing, spacious structure, intended for exceptionally big as well as smaller work, such as the manipulation of ingots for cannons, armour-plates, &c.; it comprises two big halls 262 feet long and respectively 98 feet and 82 feet wide, with an intermediate smaller hall of the same length, but 33 feet wide, the whole under the direction of Mr. Breton. In the larger hall there are the 100-ton, the 10-ton, and the 4-ton steam-hammers, which, in accordance with the programme, were seen in operation on work of different magnitudes, weighing 30, 5, and 3 tons respectively, demonstrating that the blow employed could be graded to suit the work, but there are also a 35, 15, and 2-ton hammers for a still closer gradation. Each hammer is served by necessary cranes (electrical) for rapid handling; those for the largest hammer having 150 tons capacity; various furnaces for heating before forging and annealing after forging complete the equipment of the hammer forge. In the adjoining hall the great 6000-ton press was seen at work on a 30-ton armour-plate ingot. This press, constructed at St. Chamond from the designs of Messrs. Davy Bros., is a three-cylinder press, and is provided with a full complement of furnaces and two 150-ton travelling gantries. The facility of the manipulation of both large and small work, the advantage of the spaciousness of this department, and of having the arrangements for both forging operations contiguous, were noticeable features; the forge can deal at the same time and with equal facility with a 40 to 50-ton ingot for a cannon or with smaller ones for field-guns. In forging, the cast ingot is reduced to ¼ in size and to ½ to ⅖ in weight.

The great shops marked B were next visited. They are side by side and under the same roof, each 492 feet long, each with a central alley 50 feet wide, and each with two side alleys 23 feet wide, with galleries above them, making a total floor width of 284 feet. The central alleys are provided with 50 and 30-ton travellers, whilst those in the side alleys are 5 and 10 tons. In one of the shops armour-plate and ingots, of which there was an impressive display, were being planed and also cut dry. The circular saws for cutting had numbers of small cutting tools round the periphery, and with them the ends, only two inches or so, of a 6-inch plate could be cut at the rate of 3½ to 4 in an hour. The second shop is used for the preparation of bodies of cannons and guns, shafting for war-ships, liners, and other craft. Great machine tools were to be seen by Thomas Shanks & Co. and others. One lathe is 150 feet long, and is represented at work on a big gun in Plate XXIII. Here propeller shafts 65½ feet long and 15-ton three-throw crank shafts made from a single 45-ton ingot have been dealt with. In the galleries both of this shop and the next, C, there was a splendid display of smaller machine tools obtained from foreign countries, as well as home manufacture, busy in the many refined operations connected with the production of parts of pieces of artillery and munitions of war. The special designs of Messrs. Darmencier and Dalzon were particularly admired. These engineers direct the artillery department, and it is they who have done so much to make the St. Chamond patterns celebrated both in France, our own, and other countries.

Shop C is also 492 feet long and is 105 feet wide, with a central alley 60 feet wide and two side alleys 23 feet wide, with galleries above. There are two 60 and two 10-ton electrical overhead travelling cranes. The central alley of this shop is arranged particularly for that work that has to be done when the parts are in position, and here were to be seen some of the Company's specialties in course of construction—trunks for ships' barbettes, fixed and revolving turrets, gun mountings for turrets and forts; the riveting, boring, final dressing, and fitting into position of the armour-plates of these structures was in progress, and the subsequent final touches were being given. To accommodate these great pieces of work there are many special platforms, and also to give the necessary height or for convenience of access pits are sunk in the floor and scaffoldings are erected, or there are masonry walls to support the work where necessary, as, for instance, in the case of a trunk for a barbette which was under treatment. The tools, mostly electrical, are clamped on standards or otherwise adjustably supported so as to reach any part of the work, and three or more tools could be seen in operation on different parts of the same work simultaneously. Many of the tools were of special character and design, and the precision of the work in this department was most striking. The varied and curious forms the plates had to have, the exact way they were fitted together, and the care with which even very slight imperfections were removed, particularly attracted the attention of the visitors. The boring and riveting machines for unmounted ship and boiler plates were arranged in the side alleys.

In the shop marked D, which has a 60-ton traveller, were arranged boring machines for guns and lathes for guns and shafts, and were most of them at work.

The next shop visited, E, covers an area of 2½ acres, and has three 30-ton overhead travellers and many locomotive cranes. Here the various parts of guns, carriages, and mountings are assembled and finished, and at the far side are fitted and the finished work erected. This shop was at full work, and with the vast number of machines presented a very busy and interesting scene. This department can turn out a field-gun, fully equipped with ammunition carriage, &c.

quite ready for action. These various construction shops are under the direction of Messrs. Grenier, Boliezue, Coumert, and Marthoud, who were in attendance.

On the way to the steelworks the great shop F was traversed. It is 492 feet long, and is used for machining, giving the correct dimensions and finishing armour-plates subsequent to tempering and annealing, and the long line of gigantic planes along one side, and rimers and other machine tools in the body of the halls (for there are two together), made a very marked impression on the visitors, one cutting machine attracting special notice, not only from its magnitude, but also from the ingenuity displayed in its construction; it emanated from the works of Messrs. Schneider & Cie. It consists of a long arm pivoted at one end, and having a carriage sliding in a groove in the side of the arm at the other end; a backward and forward motion is given to the carriage by means of a long worm-shaft and reversing gear, and this in turn gives a reciprocating motion to the arm. The cutting tool is attached to the underside of the arm, consequently describes a perfect curve, and inasmuch as its position may be varied as required, the curve may be given any desired radius. This shop is provided with nine overhead travelling cranes of 50 to 60 tons capacity, and an equipment of machine tools capable of dealing with 5000 tons of armour-plate a year. These may be of any dimensions, from the very largest now made downwards, and of any material desired—iron or ordinary steels, or Saint-Chamond special chrome nickel steel—and be made of any resistance obtainable at the present time; from 40 to 70 kilogrammes per square millimetre are usual resistances. The time for the great cast had arrived, and the party hurried on to the steelworks, G.

In the steelworks the furnaces are arranged on each side of a deep broad rectangular casting pit, in which great numbers of different sized and shaped ingot moulds were stacked. There are three furnaces of from 10 to 15 tons each to supply the ordinary requirements of mild, medium, and hard steels, which may amount to 60 tons a day, and besides there are four furnaces of 30 tons each to supply the metal for the specially large ingots required for big gun tubes and armour-plates, sometimes amounting to as much as 100 tons in a single mass. All the furnaces are open-hearth, and are worked basic except for special purposes, when the acid process is used. A 150-ton overhead crane controls the plant. On the occasion of the visit a 31-ton ingot intended for an armour-plate was cast, and furnished a fine pyrotechnic display. The metal was drawn from two furnaces, one on each side, simultaneously, and was run into a stationary ladle, from which, after a period of repose, it was drawn off at a definite rate into the ingot mould. Particular attention is paid not alone to the selection of the material for the steels, but also to the temperature of the bath, to the time occupied in filling the mould, and to the dimensions of the mould employed. Adjoining the steelworks is the steel-foundry H, with one 150 and two 30-ton travelling cranes. It is capable of dealing with the heaviest as well as lightest castings, and has a capacity of 100 tons of castings a month. Messrs. Pernot and Bourgeois were the engineers in charge of the steel department.

The next visit was to the armour-plate cementation and tempering houses, I and J. In the first of these, depicted in Fig. 2, there are five great furnaces for the cementation of Harvey and Krupp plates; from one of these a curved plate for a turret was withdrawn and slung horizontally on to a tabular spraying frame, the jets being at once set to work; a similar frame running on rollers was then brought into position over the plate, coupled up to the water supply, and the jets immediately set to work, so that the plate at all parts of its surface was subjected to a copious but evenly distributed play of water. All the operations were conducted with rapidity, but without any confusion. The arrangement is represented at work in the centre of Plate XXIV.

In the next house a bent armour-plate for a "blockhouse" was withdrawn from a furnace in a vertical position, and slung and plunged into the water-tank in the same position. In this house are the heating and annealing furnaces, and also the shaping presses, two in number, one about 3000, the other 3500 tons. Both are served by two 60-ton travelling cranes; the former is used for shaping before tempering, the latter to give the finishing touches after tempering, and, if necessary, the great 6000-ton press already referred to is brought into requisition. With these machines plates are given most complicated forms without any danger to the quality of the metal.

The next surprise for the visitors was a view of the new mill in course of erection at K. The rolls, housing, live rollers, and parts of the engine and the building were in place, and it is supposed that the mill will be complete in November. It has been constructed to cope with the requirements of the present day, and consists of an armour-plate mill with rolls 15 feet long and sheet-mill with rolls

11 feet 3 inches long, placed on each side of a reversible engine of 8000 horse-power. The armour-plate mill will be able to roll in a single heat a 60-ton ingot into a plate some 15 feet in width; the plate-mill will take 10-ton ingots on its live rollers, and will be able to produce sheets or plates about 10 feet wide, and of very great superficial extent. The installation includes a 100-ton crane for the armour-plate train, a 50-ton crane for the other train, the necessary furnaces for re-heating the ingots, and a great shears capable of cutting plates 2½ inches thick As an annexe to this new mill there are heating furnaces with the necessary equipment for the preparation of plates, weighing 40 tons or more.

At L is situated the grand mill, in which are the old armour-plate mill, built in 1854, but repaired and altered in 1872 and 1880, and its four reheating furnaces, two sheet-mills, and a universal mill for very large sections. The armour-plate mill was busy on a 7½-inch armour-plate for a turret; the ingot was very speedily reduced to the plate form; a considerable amount of brushwood was consumed on the plate during the operation, and the iron floor of the building became uncomfortably hot to the feet. The sheet-mills were also seen in operation. One of them can produce sheets 7 feet wide by 30 to 60 feet long, whilst the other is reserved for medium and small work, and can even turn out sheets down to $\frac{1}{12}$ or $\frac{1}{25}$ of an inch. There is another mill for rails and small sections in the adjoining shop.

The next item of the programme was the inspection of the production of weldless tires on the old mills previously referred to, and situated at M on the plan. The mills are vertical, the rough rings delivered from the forge after reheating were placed over a central roll and then also rested on two vertical wheels below; all the three were set in rapid rotation, with the result that the central hole of the rings enlarged whilst the rim diminished in width and assumed the proper form, and the rings having been brought to a certain stage in one machine, were transferred to a second and similar mill, which brought them a stage further; they were then placed over a circular hydraulic frame to receive the finishing touch, the whole operation occupying but a minute or two. Mr. Déchargé is the engineer of this department and the great mill, whilst MM. Kirmann and Louinet are the engineers in charge of the armour-plate department.

The puddling-mill N is near the tire-mill. The furnaces are mostly arranged to treat high-class pig iron for superior wrought iron or puddled steel, but there are furnaces for puddling ordinary pig iron or material employed for the making of gun-steel. The furnaces have a separate melting bed and a rotating puddling-hearth; they work charges of a ton each, and the output reaches as much as 8½ tons in twenty-four hours.

The final item in the programme before lunch was the witnessing the tempering of a gun-tube. This took place in the house specially devoted to that purpose, O on the plan. The most striking feature is the great tempering-pit, measuring about 130 feet by 85 feet by 69 feet deep from floor level. In the bottom of this pit there are several wells; the deepest, 72 feet and 10 feet in diameter, serves for tempering large work, such as big gun tubes, which attain at times nearly 50 feet in length; whilst the smaller baths or wells are used for light guns. Two of the smaller ones are in communication with the larger one, and are furnished with centrifugal pumps, in this way rendering by circulation upwards of 44,000 gallons of oil available for the tempering of large guns. At one end of the pit is the vertical reheating furnace, 69 feet high, with six super-imposed firing grates. A 50-ton travelling gantry running on rails on the floor level serves for manipulating the work; it is provided with steam windlass for doing the lifting operations and hydraulic tackle for controlling the lowering—this is to ensure rapidity with steadiness. The various stages in the operations were keenly watched—the opening of the furnace, lifting the work out (a 12-inch gun-tube), travelling it across, centring it over the bath (water in this instance), and lowering it, the whole being done with considerable expedition, and without causing the gun-tube to sway or swing. The gun-metal before tempering has a resistance of 40 to 60 kilos. per square millimetre, with a minimum elongation of 18 per cent.; after tempering the resistance is 54 to 80 kilos., with the elongation from 12 to 14 per cent. On the floor level, in convenient proximity to the tempering-pit, there are heating furnaces for small guns and for gun-rings, and a 10-ton steam crane running on a broad gauge track. An annex is attached to this house, which is equipped for the tempering and annealing special armour-piercing shells and other projectiles, for which the works are famous the world over. These are, in fact, one of the great specialties of the works. They are made of extra hard crucible steel, are vigorously hammered, and submitted to processes of tempering and annealing peculiar to this Company. Messrs. Marchais and Chalon are the engineers in charge of the tempering operations.

A return was now made to the offices, whence the carriages drove the visitors to Mr. A. de Montgolfier's residence, where a pleasant reception and an acceptable and excellent luncheon awaited them. After luncheon, Mr. A. de Montgolfier made some very kind references to the former visit of the members of the Institute, and again expressed his pleasure in seeing those members present that day. He further made some interesting allusions to the importance of the neighbourhood, to which reference has already been made, and commented particularly on the progress made at St. Chamond, of which an opportunity of forming a judgment had been afforded the visitors, and in the afternoon a further opportunity, he said, would be given of seeing the guns made in the works in action, from which he thought they would gather that French engineers had done a great deal of valuable work in the perfecting of artillery. He finally hoped that they would carry away a pleasant reminiscence of their visit in the same way as the French engineers would, long remember the visit of their British colleagues. Mr. Pye-Smith, in expressing the thanks of the members to Mr. Montgolfier for the cordial reception given them, remarked that it was one of the pleasantest and most interesting excursions the Institute had had, and on their return to England they would be able to tell their compatriots of the magnificent works in the South of France, which were turning out armour-plates and weapons of precision and of such a quality that one would be very sorry to be opposed to them. He then proposed the health of Mr. de Montgolfier and of Madame, which was heartily responded to by those present, and acknowledged by Mr. de Montgolfier. Mr. Maw then expressed in French the highly favourable impression he had obtained of the work and works that day, and proposed the health of the many gentlemen who, as guides, with Mr. H. de Montgolfier, had contributed so much to the success of the visit. This was also responded to and acknowledged, and the visitors, bidding adieu to those remaining behind, rejoined the carriages and drove off to the gun-testing ground at Langonand.

A pretty and pleasant drive terminated at the gun and plate testing firing ground. Here various Darmancier-Dalzon guns were exhibited in and out of action. First a 3-inch field-gun with recoil gear in the carriage was fired four or five times, and the carriage, although recoiling slightly, returned to the same place each time; but the gun required some re-adjustment before re-firing. A new pattern field-gun of same calibre was then fired, several rounds following in rapid succession, and without any readjustment, and yet showing at the target little or no deflection. The hydraulic recoil gear in this case is carried under the gun, which is mounted on a sliding seating upon which the gun travels at the recoil, but is immediately brought back exactly into position by the gear, the men attending sitting on the carriage the while. A mortar was fired a few times, and at each round the angle was changed with considerable facility. Various guns on the field were examined and admired, and a 10½-inch gun was fired at the rate of 8 rounds a minute with striking precision; a similar gun to this at Toulon fires ten 551-lb. shells a minute.

The party were then driven back to St. Chamond, and having bid farewell to our kind host and many of our guides of the day, were driven to the station and proceeded to St. Etienne; but two representatives of the Company were with us, and at St. Etienne Station a dinner was found all ready, having been ordered and provided by the thoughtful and generous hosts of the day. At the close of this repast, Mr. Beardmore remarked how heartily they had all appreciated the kindness and hospitality offered them that day, and how he in particular had been taken by surprise at the vastness and up-to-date character of the great works they had had the privilege of visiting.

Before terminating this notice a few general remarks may be made. Firstly, there are, of course, repairing, joinery, carpentery shops, stores, offices, &c., gas-producers every here and there; but perhaps attention may particularly be drawn to the new steelworks and the iron-foundry. The latter, at P on the plan, is arranged for castings of variable weights and dimensions, from the very smallest up to work attaining 100 tons or more, and to supply all the requirements of the works, even ingot moulds and roll-cylinders. The new steelworks, Q on the plan, are erected to supply the demand of the plate and bar mills that has outgrown the capacity of the old steelworks. There are three furnaces of 20 tons each installed. They are arranged in line in direction of their length and parallel to a long casting-pit served by steam cranes. They are for the production of ingots of less than 5 tons weight, and the first two have been yielding 100 to 120 tons a day.

A word or two about the selection of the material and the system of treatment will scarcely be out of place here. For the manufacture of artillery, for instance, which is entirely executed at St. Chamond, from casting the ingots onwards, only pig made by the Company is employed. The blast-furnaces are at Givors and Boucau. At the former, magnetic ore from their private mines in Sardinia is used, mixed with selected Spanish and Algerian ores; whilst at Boucau selected Bilbao and Bidassoa ores are exclusively used. These are coke furnaces; nevertheless the pig contains only traces of impurities: sulphur about 0·0002, phosphorus about 0·0005. But the pig used in the steel furnaces is still purer; it is prepared from the above by a special method of refining patented by the Company, and contains about 0·0001 of sulphur and often less than 0·0001 of phosphorus. For steel ingots this extra-pure pig is mixed in the furnace with wrought iron obtained by puddling the same class of pig. Rings for field-guns are made either from cast steel or puddled steel. In the latter case the puddling is done at St. Chamond with charcoal pig specially prepared for the purpose. The crude bar is submitted to a careful selection based on the grain of the steel, and then it is piled and cogged. The rings are formed by a weldless process, are carefully forged, rolled, and tempered, whilst in each batch some rings are tested for elasticity, resistance, and flexure. Rings for naval guns are made of cast steel of exactly the same quality as that used for the gun-tubes; they are manufactured by forging, boring, hollow-forging, and tempering and annealing in a manner similar to that employed with the gun-tubes. Moreover, each ring is tested, in spite of the metal having passed all the conditions of resistance, elongation, &c. The Paris Exhibition furnished plenty of evidence of the class of work turned out at St. Chamond, and a word or two must be added concerning this; in fact, any notice of these famous works written at the present time would be incomplete without some mention of the St. Chamond contribution to the Exhibition.

Professor Bauerman in his interesting account of the "Iron and Steel at the Universal Exhibition, Paris, 1900," makes succinct reference to the great castings and forgings, to the tested tires and steels, to the armoured structures, and to the artillery shown by St. Chamond, but the general character of that review precluded the introduction of detail, which here will appropriately supplement much that has been said above about these works.

The exhibits appeared in no less than six classes, thus illustrating the diversity of the work executed. An example of the capacity for handling exceptionally heavy work was furnished by an exhibit representing a finished 65-ton casting worked from an original mass of 85 tons. Evidence of quality of material was furnished in innumerable fractures and test pieces of different steels. Some of the physical data were as follows:—

Class of Steel.	Tensile Strength.	Elastic Limit.	Elongation.
	kg. per sq. mm.	kg. per sq. mm.	Per Cent.
Tire for locomotives	63·5	...	22·5
Tire for railway car	52·0	...	27·0
Tire for tramway car	76·1	...	18·0
Boiler plate, 1 inch thick	41·8	...	27·0
Extra mild plate, 0·669 inch thick . .	40·4	...	31·5
Ordinary mild steel	40·0	26·8	29·0*
Extra mild steel	36·9	21·7	39·0*
Mild for naval armaments	48·6	25·9	26·5*
Medium hard for artillery	61·4	31·3	21·0*
Medium hard for artillery . . .	65·6	33·8	20·0*
Chrome steel for shells.	80·2	48·0	19·0*
St. Chamond special	70·9	48·0	19·5*
Gun steel	70·0	45·0	18·0*
Nickel steel, 20 to 25 per cent. N_1 . .	73·5	36·7	64·0*

There was tested armour plate and sheet of all dimensions, ranging in thickness from 0·315 inch to 10·23 inch. One plate weighing 116 cwts. of St. Chamond special steel, and 10 inches thick, although indented, had resisted six rounds of a 95 lbs. projectile fired from a 5·9-inch gun at speeds varying from 2034 to 2208 feet. Another plate of the same material, $6\frac{5}{16}$ inch thick, and weighing 42½ cwts., had shattered similar projectiles fired from the same gun at successive speeds of 1716, 1800, and 1866 feet; whilst at the other end of the scale the 0·315-inch sheet for screens had resisted the regulation ½-oz. shot with an impact velocity of 1696 feet.

The display of ordnance on Darmancier and Dalzon system was strong and comprehensive—sea and land guns, cannons, howitzers, mortars, carriages, limbers, and mountings of many patterns, shell of all sizes and kinds, ammunition, and all appurtenances—making a bewildering show from which it would be useless to select an example.

Perhaps, however, the most striking exhibits were the armoured turrets and towers with equipments. One for a rapid-firing 14 calibre 4¾-inch disappearing howitzer was protected with an outer ring consisting of two curved plates of tempered cast iron fixed over the concrete base, and with an inner cylinder of 4½-inch armour plate, 8 feet 6 inches in diameter, and was covered by a slightly spherical dome of $5\frac{9}{10}$-inch plate. Another turret, for two 12-inch 40-calibre coast defence guns, revolved on a central pivot; the fixed point 4 feet 10½ feet high, 11 inches thick at the top, and 17¾ inches thick at the bottom, was of curved plates of cast iron, and formed a ring 37¾ inches in diameter. The moving body of the tower was of ¾.inch plate, and the protecting surface of the exposed part was of cemented and tempered armour plate 13¾ inches thick, with a slightly curved dome 6 inches thick. There were models of other types of turrets and towers.

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* Test pieces 0·5725 inch diameter, 3·94 inches long.

The whole display was well worthy of the great works we had seen, and the inspection of the exhibits was a gratifying complement to the enjoyable visit we had to the factory where the objects originated.

VISIT TO FIRMINY AND UNIEUX.*

At the conclusion of the excursion to the St. Chamond Works, a small party of members of the Institute proceeded to Firminy, six miles distant from St. Etienne, and were most cordially received by Mr. Hugot, the managing director of the Aciéries et Forges de Firminy (Loire), who deputed his son, Mr. Adolf Hugot, works manager, to show the party over the extensive and interesting works. The Company was founded in 1854 by Mr. François-Félix Verdié, with the special object of manufacturing what was called the "*produit mixte*," *i.e.* the pouring of crucible steel on wrought iron in order to give a hard face to iron tires and rails, crucible steel at that time being far too expensive to allow of its being used by itself in the manufacture of rails or of any but the very best tires. A sample of rail made in this way was exhibited at the Exhibition of 1855, and attracted much attention at the time.

They claim to have been the first to use the open-hearth furnace for the manufacture of rails, and in the year 1877–78 turned out some 27,000 tons of steel, the largest proportion of this output being rails. The introduction of the basic Bessemer process in the North and East of France, however, gave the death-blow to the manufacture of rails on the Loire, and the Firminy Company was obliged to find some new outlet for their products. They first established a large wireworks, which forms now a most important part of their manufacture. They make wire of all sizes and qualities, and are specially renowned for their piano-wire. Then they added largely to their steel-foundry, where they make all the different sorts of castings required for marine and locomotive engines, and at the present time are beginning to make cast-steel locomotive wheels, which have so far been adopted by very few of the French railways. Another branch which was introduced in 1880, and has been largely developed since, was the manufacture of gun-tubes, hoops, and breech-blocks for both land and marine artillery. The largest ingots, weighing upwards of 35 tons, are manipulated under a hammer of 40 tons weight, admirably provided with cranes of 50 and 60 tons lifting powers, and capacious furnaces. They have still three Siemens crucible furnaces, and make several special qualities of tool-steel, such as tungsten and chrome, besides pure carbon steels of various tempers. They also make rods for gun-barrels, cast-steel anvils, springs for railway work (both spiral and laminated), railway and tramway tires, and there is a special department for the manufacture of air-reservoirs for torpedoes.

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* Note kindly furnished by Mr. Ralph G. Scott, of the Monkbridge Ironworks, Leeds.

It will be seen by the above short sketch of the various products turned out by the Société de Firminy how admirably they have recovered from the crisis which occurred in 1880, when they were brought face to face with an entirely new condition of things which suddenly cut off their trade in steel rails, for which the whole works had been specially planned. That they were able to tide over those difficult times and to find themselves once more carried on on a wave of prosperity was due largely to the daring and pertinacity of their far-seeing director, Mr. Hugot, under whose able direction the works were remodelled to suit the changed conditions of their trade. They have a very fine exhibit at Paris of all their principal manufactures.

The party lunched with Mr. Hugot at his house, situated only 200 yards from the works in a pleasant garden with picturesque views of the hills which surround Firminy, and were driven in his carriage to the Unieux Works. There Mr. Brustlein, the managing director, showed the party over the works. They saw the forging of gun-barrel rods under old-fashioned helve-hammers, and in another part of the works a 6000-ton press doing its quiet work on a 40-ton ingot, and served by great travelling cranes spanning the shop from side to side and running right over the top of the press. These are capable of lifting and carrying weights of 60 or 70 tons. The party was delighted with the warm welcome they received, and fully appreciated the kindness with which those they met put themselves to much inconvenience to show them more than ordinary hospitality.

Excursion to St. Denis.

Sir William Roberts-Austen, the President, Mr. Snelus, Vice-President, Mr. Bennett Brough, Secretary, and about sixty members of the Institute, accompanied by a fair sprinkling of ladies, assembled on Friday, September 22, at the Paris offices of the Compagnie Française des Métaux in the Rue Volnay, to visit the works of that huge concern at St. Denis. They were taken in motor and horse cabs and in waggonettes, the drive being accomplished in rather less than an hour. St. Denis, now a typical French manufacturing place, is an historic town. It lies between the walls of Paris and the outer forts that defend the city. At St. Denis the party descended at the entrance of the old Abbey Church, where a long succession of the kings and queens of France have their last resting-place. The present church dates mainly from the twelfth century. It stands on the spot where the half-legendary French King Dagobert and the Emperor Charlemagne had previously erected chapels. It is one of the finest specimens of French Gothic architecture, but the visitors were more impressed perhaps by the crypt, where lie the remains of Louis XVI. and Marie Antoinette and of their son, than by the church proper.

After quitting the church, the party proceeded to visit the copper and lead works of their hosts, where two most interesting hours were spent. Dividing themselves into groups, the visitors were shown over the works by several of the principal officials of the Society, including Mr. Vésier, the chairman, Mr. Lair, the vice-chairman of the Board of Directors, and Mr. E. Demenge, director (member of the Iron and Steel Institute). The various operations of making copper and lead tubes, sheet-rolling, and cartridge-cap making were shown. After a lengthy tour round the works, tea, champagne, and other light refreshments were provided, and the party returned to Paris, which was reached at 6.30 P.M.

The works of the Compagnie Française des Mêtaux is one of seven works owned by that important enterprise. They employ nearly a thousand workmen and cover a superficial area of about four hectares. At St. Denis the Company specially manufactures copper and lead sheets, pipes, &c., of which the output is about 1000 tons per month. They also produce sheets of refined copper plates for the fire-boxes of locomotive engines, boiler-plates, and similar articles to the extent of about 300 tons per month. The other products of the St. Denis Works embrace cartridge cases, welded tubes, and ornamental pieces generally, to the extent of 350 tons monthly. An important part of the Company's operations consists in the manufacture of bars, wire, and profiles in copper, including wire of high conductivity for dynamos, trolleys, or electric cable transmissions, wire for what are known as "*articles de Paris*" and kindred commodities, to the extent of 400 or 500 tons monthly. It will thus be seen that the St. Denis Works possess a capacity of production of about 27,000 tons of finished copper and lead annually, which places them in the front rank of establishments engaged in the manufacture of these metals.

To keep the various machines and mills in regular operation, engines with a total of over a thousand horse-power are employed.

The principal equipment otherwise embraces a hydraulic press, which is used to produce brass or copper pipes. The principal sheet-mill has rolls 144 inches long, 3 metres 60 c., is reversible, and can roll sheets 15 metres long and plates up to 800 kilos. weight. The plant which is employed in the wireworks is partly actuated by electric power and admits of the employment of unusual speed.

There are twenty-four gas-producers in the works, which are used to supply the various heating furnaces, the latter being partly of the usual and partly of an exceptional type. The refining furnaces used for copper have a capacity of 10 tons. Attached to the works is a chemical laboratory of the latest type, which is presided over by Mr. Hollard, a chemist, who is well known for his electrical researches.

THE "SOCIÉTÉ D'ENCOURAGEMENT."

The Société d'Encouragement pour l'Industrie Nationale, whose rooms were kindly lent for the meeting, was founded in 1801 for the advancement of all branches of French industry. It awards prizes and medals for inventions and improvements introduced into the arts. It carries out experiments and tests in order to ascertain the value of new processes brought before it, and publishes a valuable monthly *Bulletin*. It awards medals to artisans who have distinguished themselves by their conduct or work, and it assists inventors whose age or infirmities render them incapable of supporting themselves. Ordinary members pay to the Society an annual subscription of 36 francs.

The history of the Société d'Encouragement may partially be read on the walls of the hall where meetings are held, in the handsome portraits of past-presidents and other men of mark who have been closely interested in its progress. There are about a dozen portraits in all, including those of the Comte de Chaptal, president from 1801–32; Baron L. J. T. Thenard (1833–45); J. B. Dumas, the famous chemist, president from 1846–84; Edmond Becquerel, president from 1885–86; Haton de la Goupillière, director of the Paris School of Mines, in his uniform as member of the Paris Academy of Sciences (president 1889–91); and General Poncelet, well known for his researches in mechanics. On the walls of the entrance-hall to the Société's house one reads such names as those of Lavoisier, Vanquelin, and Gay Lussac, who are amongst the most cherished sons of France, whose names will be for ever connected with the scientific progress of the nineteenth century.

OBITUARY.

George Frederick Armstrong, Professor of Engineering in the University of Edinburgh, died at his home in Grasmere, Westmorland, on November 16, 1900. Born at Doncaster in 1842, he was a student of Jesus College, Cambridge. As he had early shown a fondness for mechanical pursuits, he subsequently was educated professionally in the engineering department of King's College, London, in the plant and locomotive shops of the Great Northern Railway, and in the office of the engineer-in-chief of that Company. Of the Great Northern Railway engineering staff he was a member for several years, and was employed in superintending many important works, and in the maintenance of the line. Thence he went into private practice in London. In 1869 he became engineer to the promoters of the Isle of Man railways; and in 1871 he took up the teaching art, when he was elected first Professor of Engineering in the new Applied Science School at the McGill University, Montreal. Five years later he recrossed the Atlantic to take up similar work in the Yorkshire College of Science, Leeds; and in 1885 was appointed by the Crown to succeed the late Professor Fleeming Jenkin as Regius Professor of Engineering in the University of Edinburgh. In his inaugural address at that time he dealt with the question of the spread of technical education at home—a subject in which he never ceased to take the deepest interest. During his term of office, the engineering department of the University was greatly improved and advanced, and the laboratory in connection with it fitted up under his supervision by the aid of the funds of the Fulton bequest. He was a man of great business capacity and administrative ability, and his teaching in his own special department was of a thoroughly practical nature. He gave particular attention to sanitary work and to questions regarding water supply, and in this connection it may be mentioned that he was engineering adviser under the Public Health Act to the Local Government Board for Scotland. He took an active share in the work of the two Edinburgh International Exhibitions, 1885 and 1890, in the latter of which he was convener of the Engineering and Machinery Committee and vice-chairman of the Executive Council. He was president of the Sanitary Engineering Section of the British

Institute of Public Health in Edinburgh in 1893, and delivered an address; and in connection with the last meeting in Edinburgh of the British Association he acted as local secretary. During the summer and autumn of 1879 he undertook an extensive series of observations and experiments with a view of determining the diurnal variation in the amount of carbon dioxide in the air, the results of which were communicated in a paper to the Royal Society, and have since been accepted as a standard of reference on the Continent as well as in this country. In 1889 the Council of King's College, London, elected Professor Armstrong to the Fellowship of the College. He was an examiner for science degrees in the Departments of Engineering, Public Health, and Agriculture in the University of Edinburgh, hon. president of the East of Scotland Engineering Association, a member of the Institution of Civil Engineers, and a Fellow of the Royal Society of Edinburgh. He was elected a member of the Iron and Steel Institute in 1889, and acted as local Honorary Secretary in connection with the Institute's meeting in Edinburgh in 1888.

JOHN HARRIS EDGE died in October 1900 at Shifnal, Shropshire, at the age of sixty-eight. He was the senior partner in the well-known firm of Edge & Sons of the Coalport Works of Shifnal, manufacturers of wire ropes, chains, brick and tile machinery. He was the grandson of the late Mr. Benjamin Edge, who founded the business about the year 1800, and invented the flat-link wood-keyed chain that superseded hemp ropes for winding purposes in pits before wire ropes were adopted. He was elected a member of the Iron and Steel Institute in 1880.

WILLIAM FLETCHER, of Brigham Hill, Cockermouth, whose death occurred on August 6, 1900, was a prominent man in Cumberland. Born in 1831, he was the third son of Mr. J. W. Fletcher, of Tarn Bank, a member of the Society of Friends, and representative of an old Cumberland family. When quite a young man he took part in local public affairs, and being interested in the coal trade, he saw the importance of improving the railway facilities of the district. He was an active promoter of the Cockermouth, Keswick, and Penrith Railway, of which he was one of the first directors, and of the Cleator and Workington Junction Railway, of which he was chairman; and he helped forward the transfer of the Cockermouth and Workington Railway to the London and North-Western Company. He was at one time managing director of the West Cumberland Iron and Steel Company, and latterly of the

Allerdale Coal Company; he was also chairman of the Moresby Coal Company. He had great influence in the coal trade, and as chairman of the Cumberland Conciliation Board he often helped to preserve peace when strikes were threatened. The local community had the benefit of his services in various departments of local government. He was an advanced Liberal in politics, and on the death of his elder brother, Mr. Isaac Fletcher, in 1879, he succeeded him as M.P. for the borough of Cockermouth, but he only held the seat until the following year, when a general election occurred, and for personal reasons he retired in favour of his friend, Mr. Edward Waugh. He continued, however, to take an active part in local politics. He was an original member of the Iron and Steel Institute.

John Lee Hodgson died at his residence, Hooley Range, Heaton Moor, Stockport, on January 31, 1900, at the age of seventy-five. He was born at Stanhope, in the county of Durham, and, like the late Mr. Daniel Adamson (Past-President of the Iron and Steel Institute), was apprenticed at the age of thirteen to the late Mr. Timothy Hackworth at the Shildon Works of the Stockton and Darlington Railway Company, where he remained until 1849. From the Shildon Works he went to London to Messrs. Maudsley, Son, and Field, where he stayed until 1852, when he left for Stockport and joined the firm of Messrs. Robert Gordon & Co., Heaton Foundry, as head-draughtsman (Mr. Daniel Adamson being their manager). Here he stayed until the firm changed hands, the concern being taken over by Messrs. Emmerson & Murgatroyd. He afterwards went to Chester to Messrs. J. Rigg, but only stayed with them a short time. Messrs. Emmerson & Murgatroyd having taken on some large contracts, he again entered their service, and from thence carried out some most important works, including the construction of a large hydraulic-lift graving-dock (Clark's patent) for Bombay, and a similar one, but smaller, for Malta. He also in the year 1875 constructed and erected, in conjunction with Mr. S. Duer, the Anderton hydraulic canal lift, for the Weaver Navigation, Northwich, Cheshire. Mr. Hodgson remained with Messrs. Emmerson & Murgatroyd until they closed, and subsequently until his death he practised as a consulting engineer in Manchester and Stockport. He was elected a member of the Iron and Steel Institute in 1873.

John Robert Jefferies died on September 12, 1900, at the age of sixty. He was for many years the manager of the export department of the firm of Ransomes, Sims, & Jefferies, Limited, Ipswich. He was born in 1840 at Great Barford, Bedfordshire, and in 1856 entered the Orwell Works, Ipswich, as an articled pupil. In 1866 he married a daughter of the late Mr. James Allen Ransome, a member of the firm, and was taken into partnership, the business then existing under the title of Ransomes, Sims, & Head. In 1884, when it was converted into a limited liability company, Mr Jefferies became a managing director. In 1882 he was elected one of six representatives of the Burgesses of Ipswich on the Dock Commission, and in September of the same year he was chosen a member of the Committee of Management. He took the greatest interest in the improvement of the port, and was a most regular attendant at the meetings in connection therewith. On the Ipswich Chamber of Commerce and Shipping being formed in 1884, he succeeded Mr. Edward Packard, who was the first chairman, and in 1900 he was re-elected to that position. He was also that year's chairman of the Agricultural Engineers' Association, a member of the Institute of Mechanical Engineers, and a Justice of the Peace for the borough. He was elected a member of the Iron and Steel Institute in 1879.

James Jones, of Brookland, Swansea, died on November 16, 1899, in his sixty-third year. He was High Sheriff of Cardiganshire, a Justice of the Peace for Cardiganshire and Glamorganshire, and an ex-Mayor of Swansea. He officially attended Bristol in connection with the visit to that city of Her Majesty the Queen the day before his death. Feeling somewhat unwell, he telegraphed for his son, Mr. R. W. Jones, who joined him, and they left Bristol for Swansea. He died during the journey. He was very popular with all classes. Amiable and generous, he was welcomed everywhere. As Mayor of Swansea he dispensed lavish hospitality, and for many years he played a prominent part in the municipal government of Swansea. He was born at Aberystwyth in 1837, but came to Swansea somewhat early in life, and entered the service of Messrs. Philips & Son, wholesale grocers, Castle Square, and was permanently engaged as a traveller. About twelve years after he started business on his own account. He was remarkably successful. He built up a great business, and retired from it several years ago a very wealthy man. He took an active interest in friendly society work. He was patron of the Loyal James Jones Lodge (Independent Order of Foresters, Manchester Union), and very frequently he paid the subscriptions of large numbers of members, in his own as well as in other lodges. He was a member of the Board of Guardians for many years. He was part proprietor (jointly with David Richards, Esq.) of the Dynevor Tin Plate Works, Pantyffynon, near Swansea, and was also one of the founders and director of Weaver's Flour Mills, Swansea. He was elected a member of the Iron and Steel Institute in 1890.

Claude John Morris died on October 8, 1900, at his residence, Rutland Lodge, Buxton, at the age of fifty-eight years. He was managing director of Messrs. Rylands Brothers, Limited, wire manufacturers, of Church Street, Warrington. He was a county magistrate for Lancashire, and he was one of the most regular attenders at the Warrington County Petty Sessions. He was for many years a resident in Altrincham, and was the chairman of the Altrincham Liberal Council, being a Liberal in politics. He last sat at the Warrington Court on 19th September, and was present at the celebration of the attainment of the dignity of a county borough by Warrington on the 1st October, when he appeared to be in the best of health: he caught a chill while returning home, from which he never recovered. He was elected a member of the Iron and Steel Institute in 1896.

Daniel Pidgeon died at Assuan, Egypt, on March 13, 1900, at the age of sixty-seven. He was an articled pupil of Messrs. Barrett, Exall, & Andrews of Reading, and was subsequently employed by Mr. Thomas Hawksley and by Messrs. Cochrane & Co. of Dudley. In 1862 he settled at Banbury as a junior partner in Sir Bernhard Samuelson's works. In 1876 he retired from active work. He was a member of Council of the Royal Agricultural Society, a Fellow of the Geological Society, and an Associate of the Institution of Civil Engineers. He was the author of books describing his experiences in the United States, and of numerous scientific memoirs. He was elected a member of the Iron and Steel Institute in 1870.

Benjamin Round died at his residence, Court Oak, Harborne, Staffordshire, on October 22, 1900. His death occurred whilst he was reading his newspaper, but it is believed that it was hastened by violent exertion which he had undertaken a few days previously at the Hange Furnaces, Tividale. The furnaces were being dismantled, and Mr. Round took up a hammer and helped in smashing some castings which were being got ready for the forthcoming sale of the plant and works. The Hange Furnaces have been celebrated for many years for the production of a brand of that all-mine pig iron which years ago made the iron industry of South Staffordshire famous. The dismantling is due to the fact that the furnaces have become obsolete, while the colliery, like so many more in the district, is waterlogged. Mr. Round was the third son of Mr. John Round, of Daisy Bank, near Coseley. He was born on February 2, 1836, and was educated at Harrow School. Afterwards he joined his brothers at Tividale in working the Hange Furnaces and Collieries. In 1888 he formed, with four friends, a syndicate to acquire and work Rixon's blast-furnaces at Wellingborough, now known as the Wellingborough Iron Company, Limited, of which he was managing director until his death. He was a director and vice-chairman of the County of Stafford Bank. He was an original member of the Iron and Steel Institute.

WILLIAM RYLAND died on October 11, 1900, at his residence, Rye Lodge, Nether Edge, Sheffield. He was principally connected with Ryland's Electro-plating Company, Limited. He was elected a member of the Iron and Steel Institute in 1890.

HERBERT SARTORIS died at Ostend on August 30, 1900. Born on November 12, 1845, he was educated at Eton, and after leaving there served his time with Messrs. Stevenson & Son, engineers, of Newcastle-on-Tyne. After his term of service he went to the Continent, and had a great deal to do with the construction of railways in the North of France and Belgium. After spending about ten years on the Continent he returned to England for a short time, and after that he went to Hungary, Egypt, and Brazil on various railway constructions. He was engaged at Islip Furnaces on his return, and shortly after that he and Mr. F. W. Preston took over the ironstone pits of Messrs. Wallis & Manners, near Kettering, in 1876. The present furnaces on the Rockingham Road were begun and blown-in in 1878. He was managing director with Mr. Preston since the commencement of the works. He was elected a member of the Iron and Steel Institute in 1877.

CHARLES TYLDEN-WRIGHT, who died on August 8, 1900, at his residence, Mapperley Hall, Nottingham, at the age of sixty-eight, after a few days' illness, was one of the leading authorities on coal-mining in Great Britain. After a course of study at the Royal School of Mines and at Freiberg and Liége, he occupied from 1858 to 1886 the position of managing director of Shireoakes Colliery. From 1886 to 1890 he was chief agent to the Earl of Dudley. He was chairman of the Shireoaks Company, director of the Monckton Mains Collieries, and of the Sheffield and South Yorkshire Navigation Company. He was viewer to the Duke of St. Albans, to Mr. Webb, of Newstead Abbey, and to the Duchy of Lancaster. He was a member of the Institution of Civil Engineers and a Fellow of the Geological Society, and was the author of several important memoirs on technical subjects. He was a Justice of the Peace for Nottingham, Worcestershire, and Staffordshire. He was elected a member of the Iron and Steel Institute in 1889.

Charles J. Valentine died in November 1900, at the age of sixty-three. He was a director and one of the original partners in the concern now known as the Moss Bay Hæmatite Iron and Steel Company of Workington. Mr. Valentine was a native of Stockport. He started life as an accountant, and afterwards with his brothers-in-law, the Messrs. Kirk, established the Workington Iron and Steel Company, which was very successful. In 1885 Mr. Valentine beat Sir Wilfred Lawson in the contest for the parliamentary seat of the Cockermouth Division. He took an active part in local and county affairs. He was chairman of the Local Board for Workington before the town was incorporated, and was a Justice of the Peace. He was a generous supporter of all religious and social movements for the betterment of the people. He was elected a member of the Iron and Steel Institute in 1874.

Thomas Vaughan died on November 30, 1900. He was son of the late Mr. John Vaughan of Middlesbrough, the earliest pioneer of the Cleveland iron trade, and the discoverer of Cleveland ironstone fifty years ago in Sir J. H. Lowther's grounds at Wilton, near Redcar. By his father's will Mr. Thomas Vaughan was bequeathed personal property of over a million pounds in value. A good deal of this money was sunk in industrial enterprises of various kinds, and when the crisis in the iron trade in 1877–78 occurred, he, along with many other leading Teeside ironmasters, sustained losses from which he never recovered. He was from 1866 to 1875 a member of the Middlesbrough Corporation, and in 1871–72 he was Mayor of the borough. He was twice invited to contest Middlesbrough when parliamentary vacancies occurred, and once he was given the opportunity to stand for Whitby, but each time he declined. He was created a Deputy-Lieutenant for Yorkshire, and a Justice of the Peace both for Middlesbrough and for the North Riding. He was an original member of the Iron and Steel Institute.

ADDITIONS TO THE LIBRARY

DURING THE SECOND HALF OF 1900.

Title.	By whom Presented.
"Lloyd's Register of British and Foreign Shipping." Vols. i. and ii., with Rules and Regulations. London. 1900.	The Secretary.
"British Corporation for the Survey and Registry of Shipping." Glasgow. 1900.	The Secretary.
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"The American and Foreign Iron Trades in 1899." By J. M. Swank. Washington. 1900.	The Author.
"Lister's English and French Tabulated Weights of Steel." Middlesbrough. 1900.	Bennett H. Brough.
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"Statut de la Fondation Nobel." Stockholm. 1900.	The Board of Education.
"Mines and Quarries: General Report and Statistics for 1899." Part III. Output. London. 1900.	The Under-Secretary of State.
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"Studio sulli Condizioni dell' Industria Siderurgica in Lombardia." Rome. 1899.	Bennett H. Brough.
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"Capital and Labour in Coal-Mining." By J. B. Simpson. Newcastle-upon-Tyne. 1900.	The Author.
"La Tour de Trois Metres." By G. Eiffel. Paris. 2 vols. 1900.	The Author.
"Report of the Department of Mines for the Year 1899." Perth. 1900.	The Under-Secretary for Mines, Perth.
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"Travaux Scientifiques exécutés à la tour de trois cents mètres." By G. Eiffel. Paris. 1900.	The Author.

INSTITUTIONS.

The Publications of the Institute are exchanged for those of the following Institutions :—

LONDON.

Board of Trade.
British Fire Prevention Committee.
Chemical Society.
City and Guilds Institute.
Geological Society.
H.M. Patent Office.
Imperial Institute.
Institution of Civil Engineers.
Institution of Electrical Engineers.
Institution of Mechanical Engineers.
Institution of Mining and Metallurgy.
Institution of Naval Architects.

Royal Artillery Institution.
Royal Institute of British Architects.
Royal Institution.
Royal Society.
Royal Statistical Society.
Royal United Service Institution.
Society of Arts.
Society of Chemical Industry.
Society of Engineers.
University College.

PROVINCIAL.

Cleveland Institution of Engineers.
Engineering Society (Leeds).
Hull and District Institution of Engineers.
Institution of Engineers and Shipbuilders in Scotland.
Liverpool Engineering Society.
Manchester Association of Engineers.
Manchester Geological Society.
Mason College (Birmingham).
Merchant Venturers' Technical College (Bristol).
Mining Institute of Scotland.
North-East Coast Institution of Engineers.
North of England Institute of Mining and Mechanical Engineers.
Royal Dublin Society.
Sheffield Technical School.
South Staffordshire Institute of Iron and Steel Works Managers.
South Staffordshire Ironmasters' Association.
South Wales Institute of Engineers.
University College of South Wales.
West of Scotland Iron and Steel Institute.

COLONIAL AND FOREIGN.

Colonial.

Australasian Institute of Mining Engineers.
Canadian Institute.
Canadian Mining Institute.
Canadian Society of Civil Engineers.
Department of Mines, Sydney.
Department of Mines, Melbourne.
Geological Survey of Canada.
Geological Survey of India.
Geological Survey of New South Wales.
Mining Society of Nova Scotia.
Royal Society of New South Wales.

United States.

Alabama Industrial and Scientific Society.
American Association for the Advancement of Science.
American Institute of Mining Engineers.
American Iron and Steel Association.
American Society of Civil Engineers.
American Society of Mechanical Engineers.
Department of Labour.
Engineers' Society of Western Pennsylvania.
Franklin Institute.
New York Academy of Sciences.
Ordnance Office, War Department.
School of Mines, Columbia College, New York.
Smithsonian Institute.
United States Geological Survey.

Austria.

K.k. geologische Reichsanstalt.
Oesterr. Ingenieur- und Architekten-Verein.

Belgium.

Association des Ingénieurs sortis de l'Ecole des Mines de Liége.
Ministère de l'Interieur.

France.

Comité des Forges.
"Revue Maritime." Ministère de la Marine.
Société d'Encouragement pour l'Industrie Nationale.
Société de l'Industrie Minérale.
Société des Anciens Élèves des Écoles Nationales d'Arts et Métiers.
Société des Ingénieurs Civils.
Société Scientifique Industrielle de Marseille.

Denmark.

Tekniske Foreningen.

Germany.

Königliche Bergakademie in Freiberg.
Königliche Technische Versuchsanstalt.
Verein Deutscher Eisenhüttenleute. (Journal "Stahl und Eisen.")
Verein Deutscher Ingenieure.

Italy.

Reale Accademia dei Lincei.

Sweden.

Jernkontoret

JOURNALS.

The following periodicals have been presented by their respective Editors:—

UNITED KINGDOM.

"Boring and Drilling."
"Citizen."
"Coal and Iron."
"Commerce."
"Contract Journal."
"Colliery Guardian."
"Electrician."
"Electrical Engineer."
"Engineer."
"Engineer and Iron Trades Advertiser."
"Engineering."
"Engineers' Gazette."
"Feilden's Magazine."
"Hardwareman."
"Hardware Trade Journal."
"Invention."
"Iron and Steel Trades Journal."
"Iron and Coal Trades Review."
"Ironmonger."
"Iron Trade Circular."
"Machinery Market."
"Marine Engineer."
"Mechanical Engineer."
"Mechanical Progress."
"Petroleum Review."
"Phillips' Monthly Register."
"Plumber and Decorator."
"Practical Engineer."
"Railway World."
"Science and Art of Mining."
"Shipping World."
"Statist."
"Steamship."
"The London Technical Education Gazette."
"Tool and Machinery Register."

COLONIAL AND FOREIGN.

Colonial.

"Canadian Mining Review."
"Indian Engineering."

United States.

"Age of Steel."
"American Foundrymen's Association."
"American Journal of Science."

"American Machinist."
"American Manufacturer."
"Bradstreet's."
"Cassier's Magazine."
"Engineering and Mining Journal."
"Engineering Magazine."
"Engineering News."
"Iron Age."
"Iron Trade Review."
"Letter of the Anthracite Coal Operators' Association."
"Metallographist."
"Mines and Minerals."
"Railroad Gazette."
"Report of Proceedings of the Master Car Builders' Association."
"Tin and Terne."

Austria.
"Oesterr. Zeitschrift für Berg- und Hüttenwesen."

Belgium.
"Bulletin de l'Union des Charbonnages de Liége."
"Moniteur des Intérêts Matériels."
"Revue Universelle des Mines."

France.
"Annales des Mines."
"L'Echo des Mines."
"Le Génie Civil."
"Le Mois Scientifique et Industriel."
"Portefeuille Économique."

Germany.
"Annalen für Gewerbe und Bauwesen."
"Chemiker Zeitung."
"Glückauf."
"Verein Deutscher Eisen und Stahl Industrieller."
"Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate."
"Zeitschrift für praktische Geologie."
"Zeitschrift für Werkzeugmaschinen und Werkzeuge."

Italy.
"L'Industria."
"Rassegna Mineraria."

Spain.
"España."
"Revista Minera."

Sweden.
"Teknisk Tidskrift."

SECTION II.

NOTES ON THE PROGRESS OF THE HOME AND FOREIGN IRON AND STEEL INDUSTRIES.

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In the preparation of these Notes the Editor has been assisted by E. J. Ball, Ph.D., and H. G. Graves, Assoc. R.S.M.

IRON ORES.

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I.—*OCCURRENCE AND COMPOSITION.*

The Genesis of Ore Deposits.—Several lengthy papers on the origin of ore deposits have recently been published. Charles R. Keyes [*] deals with the origin and classification of ore deposits. He considers the basis of classification and presents a scheme.

S. F. Emmons [†] discusses the secondary enrichment of ore deposits, giving a statement of his belief and arguments in its favour.

In a course of four Cantor Lectures delivered before the Society of Arts by Bennett H. Brough,[‡] on the nature and yield of metalliferous deposits, the author incidentally dealt with the classification of ore deposits.

The simplest classification divides them into (1) beds, (2) veins, and (3) masses. This classification has proved well adapted for practical use. The more elaborate systems of classification that have from time to time been proposed are fully discussed, the classifications dealt with being those of Agricola (1555), Burat (1855), B. von Cotta (1853), Grimm (1869), J. A. Phillips (1884), A. von Groddeck (1878), F. Posepný (1880), Sir A. Geikie (1882), H. S. Monroe (1892), H. F. Kemp (1892), H. Louis (1896), H. Hoefer (1897), and G. Gürich (1899). The last-named investigator uses the mode of concentration as the basis of classification. The concentration may take place with or without a change in the state of aggregation. In the former case the passage into the solid state is from a state of vapour, from a molten state, or from a state of aqueous solution. Consequently the following classes of ore deposits are distinguished:—

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[*] *Transactions of the American Institute of Mining Engineers*, February 1900.

[†] *Ibid.*

[‡] *Journal of the Society of Arts*, vol. xlviii. pp. 673–687.

I. Sublimation deposits: (*a*) syngenetic, in which the sublimation of the vapours takes place simultaneously with the solidification and within a solidifying magma, *e.g.* tin ore deposits; (*b*) epigenetic, in which crusts are formed coating fissures; (*c*) metagenetic, in which the constituents of a rock are dissolved by pneumatolysis and replaced by metallic substances.

II. Magmatic, or solidifying deposits: (*a*) syngenetic, representing the usual form of magmatic deposit as described by Vogt; (*b*) epigenetic, only imaginable if an apophysis of a magma within the enclosing rock consists of a metallic band; (*c*) metagenetic, hardly imaginable.

III. Precipitation deposits: (*a*) syngenetic, in which the chemical precipitation takes place simultaneously with the sedimentation, the deposit being formed simultaneously with the surrounding rock, *e.g.* seams, beds; (*b*) diagenetic, in which the concentration takes place on the muddy floor of a lake, *e.g.* concretionary nodules of clay iron ore; (*c*) epigenetic, in which the deposit is formed subsequently to the surrounding rock, *e.g.* veins, cave fillings; (*d*) metagenetic, in which the soluble constituents of a rock are dissolved, transported, and the metallic substance precipitated, the deposit being formed subsequently to the enclosing rock, but growing at the expense of the latter.

IV. Separation deposits: (*a*) residual deposits, formed by chemical concentration, a soluble rock constituent, *e.g.* lime, being carried away, and a metallic substance, *e.g.* brown iron ore, remaining unaltered; (*b*) detrital deposits, formed by mechanical concentration, *e.g.* dry placers, alluvial deposits.

In view of the apparent impossibility of definitely determining the genesis of a given deposit, it may be questioned how far it is advisable to adopt a genetic classification. Probably, however, by employing that system of classification, an observer would be induced to make a more thorough examination than if he were required merely to define the deposit by its outward form. Any efforts to introduce improvements in mining must, however, subordinate theory to practical requirements.

The Styrian Iron Mountain.—The geological structure of the celebrated iron ore mountain of Styria, which was visited by the Iron and Steel Institute in 1882, has been investigated by M. Vacek,[*] who gives a section of the mountain showing the complicated character of its geological structure. The mountain is situated at the contact of Triassic rocks and Palæozoic and crystalline rocks. It forms a cone 5000 feet in height, and is composed of no less than four series of beds stratigraphically independent—namely, at the base (1) gneiss, the oldest rock of the whole district; (2) Lower Devonian beds deposited unconformably above the gneiss; (3) the ironstone formation; and lastly (4) the Werfener beds.

An account is published [†] of the iron industry of Styria in the fifteenth and sixteenth centuries. Special mention is made of the influence exerted by Peter Pögel and his son, in the latter half of the fifteenth and the first half of the sixteenth centuries, and of the Am Thörl iron-works. The rise and subsequent decadence of the Styrian industry of that period is shown to have been closely connected with the fortunes of the Pögel family.

Iron Ore in Bosnia.—The iron ore district of Vares, in Bosnia, has been described in a work of 94 pages by F. Katzer.[‡] Illustrated by a coloured geological map and by 22 illustrations in the text, it deals exhaustively with the geological structure of the district, the iron ore deposits, and the deposits of manganese and sulphide ores. The iron ore deposits have long been known. Indeed, they are believed to have been worked in pre-Roman times. The beds are of Triassic age and occur in association with limestone. The deposits are described as being among the richest in Europe.

Iron Ore in France.—F. Villain recently read before a technical society at Nancy an important paper on the iron ore deposits of Meurthe-et-Moselle. It is published in full in the *Revue Industrielle de l'Est* of July 1, accompanied by a map of the mines of the Briey basin, a contour map of the Briey deposit, various sections of the ore-bearing beds, section of the Briey basin between Sancy and Eton and between Mercy and Avril, and a geological sketch map of the East of France.

Iron Ore in Lorraine.—A map of the minette ore district of Lorraine and Luxemburg, together with some illustrations and a general account of the ore and its use is given.* Some of the works are also described in a series of articles, of which the one referred to above is the first.

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[*] *Jahrbuch der k.k. geologischen Reichsanstalt*, vol. l. pp. 23–32.

[†] *Oesterr.-Ung. Montan- und Met. Zeitung*, 1900, No. 14; *Stahl und Eisen*, vol. xx. pp. 614–615.

[‡] *Berg- und Hüttenmännisches Jahrbuch der k.k. Bergakademien*, vol. xlviii. pp. 99–189.

Iron Ore in Elba.—G. Tonietti, the British Vice-Consul in Elba,† gives some particulars of the trade of the island, and states that 251,095 tons of iron ore were exported in 1899, of which about two-fifths came to Great Britain. The exports in 1898 were 25,173 tons less. Two blast-furnaces are to be erected on the island in the district of Portoferraio, and it is probable that very little ore will be exported in the future, as it will be retained for local consumption.

Iron Ore in Norway.—According to H. L. Geissel,‡ the geological formation of the Dunderland Valley is glacial, post-glacial, and Cambrian, in which the iron ore is found. The deposits are situated in six districts, viz., Vesteraalid, Bjornhei, Urtvand, Lilleaaen, Strandjord, Nord Dunderland. These deposits are practically all connected for a distance of 15 miles, and are mostly from 50 to 100 feet in width. Taking the deposits at 600 feet in height from the level of the river, no less than 840,000,000 tons of iron ore may be available there, of which it is estimated that about a quarter contains 55 to 65 per cent. of iron.

The rock formation is mostly quartz, with some small quantities of pyroxene, amphibole, epidote, granite, mica, and felspar. The quantity of phosphorus found differs somewhat in the various lodes, but the average is thought not to exceed 0·15 per cent.; and in most of the samples it has been so little that the ore is suitable for Bessemer working. Analyses of the ore are as follows:—

Fe_2O_3	82·21	68·03
Fe_3O_4	5·07	4·23
SiO_2	8·00	20·35
Al_2O_3	1·06	1·79
MnO	0·21	0·27
CaO	2·70	3·60
MgO	0·29	0·75
P_2O_5	0·121	0·565
S	0·010	0·025
Totals	99·67	99·81
Fe	61·32	50·63
P	0·053	0·248

Much of the ore could be worked open-cast; water power and timber are abundant.

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* *Iron Age*, June 28, 1900, pp. 1–4.

† Foreign Office Report, July 1900.

‡ *Engineering News*, vol. xliii. p. 276.

Iron Ore in Russia.—In a paper read at the International Mining Congress at Paris, Szymanowsky[*] described the Krivoï-Rog ore deposits, and the present conditions of the metallurgical industry in Southern Russia. Plans of the deposits are given and their geology is discussed. It is considered that the mineral wealth of Krivoï-Rog constitutes the foundation of the iron industry in South Russia, the other productive patches of the so-called crystalline schists (of which the Krivoï-Rog basin forms part) containing only very small quantities of iron ore. The Krivoï-Rog reserves, estimated from trustworthy data, are sufficient to maintain this industry for thirty years. Although the available quantity of Kertch ore is enormous, it cannot be used in works far removed from the deposit; and even at those near Kertch the local ore can scarcely be employed in larger proportions than 30 to 40 per cent. of the charge.

Iron Ore in Spain.—An account has been published[†] of a company which has been formed to work the Carreño iron ore mines in Asturias. There are six beds of hæmatite of Devonian age, the amount of ore available being estimated at 60,000,000 tons. Typical analyses of the ore yielded 50·89, 49·88, and 47·59 per cent. of iron.

Swedish Iron Ores.—The following are analyses of the Swedish iron ores exhibited at the Paris Exhibition:[‡]—

Ore from	Iron.	Phosphorus.	Sulphur.
	Per Cent.	Per Cent.	Per Cent.
Johannesberg . .	51·4	0·002	0·030
Burängsberg . .	55·5	0·005	0·025
Bispberg . . .	68·1	0·003	0·003
Stripa . . .	52·0	0·008	0·003

Iron Ore Deposits in Northern Sweden.—In 1899 two expeditions were sent out officially for the purpose of examining the iron ore deposits of the province of Norbotten, and a report of their work has recently been published by F. Svenonius[§] and W. Petersson. Altogether forty-four different ore deposits were examined. Most of them occur in syenite, syenite porphyry, and in syenite granulite; very few are in greenstone, and none at all in the granite Cambrian-Silurian deposits, or in the limestones, sandstones, and conglomerates that are found with the syenite rocks. Generally speaking, the results show, that while some of the larger ore fields are very promising, such as those of Svappavara, Leveäniemi, Tuolluvara, Ekströmsberg, and perhaps Mertainen, others, that seemed at one time very hopeful, now hold out little promise of lasting value. The iron ore deposits examined were of two main kinds, one in which the ore crops out at the surface, and the other in which it is covered, and its presence detected only by means of the magnetometer. To the first of these two classes belongs the Svappavara field. This was known even in the seventeenth century. Recent investigations have shown it to be a far larger and richer deposit than was formerly believed to be the case. This ore deposit is now known to extend for 0·8 mile with an average width of 131 feet. The quantity of ore in this deposit which lies above the level of the projected Ofoten railway is about 13,000,000 tons. The ore at the northern end of the deposit consists of magnetite, and that at the southern end of hæmatite. The former is richer in apatite and calcium carbonate than the latter. The average percentage of iron is from 61 to 62, with 1 per cent. of phosphorus, while the percentage of calcium carbonate varies from 1 to 20. The ore contains from 0·9 to 0·45 per cent. of titanium, and from 0·12 to 0·060 per cent. of sulphur. It is found in syenitic granulite.

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[*] *Bulletin de la Société de l'Industrie Minérale* (advance proof).

[†] *Revista Minera*, vol. li. p. 465.

[‡] *Stahl und Eisen*, vol. xx. p. 636.

[§] *Jernkontorets Annaler*, 1900, pp. 215–368.

Analyses of the magnetite yielded :—

	Per Cent.
Iron	59·390 to 65·850
Phosphorus	0·715 ,, 1·810
Sulphur	0·018 ,, 0·027
Titanic acid	nil ,, 0·400
Calcium carbonate	1·910 ,, 8·210

Other analyses show this ore to consist of from 59·66 to 90·94 per cent. of magnetite, 3·41 to 17·28 per cent. of apatite, and 1·91 to 20·66 per cent. of calcium carbonate. Of other minerals there was less than 4 per cent., except in one instance.

The hæmatite is finely granular, but not so close in texture as the magnetite. Average samples of this ore in its raw state showed :—

Iron.	Phosphorus.	Sulphur.
49·94 to 70·09	0·045 to 1·880	0·007 to 0·038

The calcium carbonate varies in eleven assays of average samples from 1·13 to 11·76 per cent. This ore consists of iron glance, apatite, and calc spar; and while somewhat richer in iron than the black ore, is poorer in phosphorus and calcium carbonate. Titanic acid and sulphur are low in both cases.

This Svappavara deposit consists of a system of elongated lenses, surrounded by syenitic granulite, striking north and south and dipping sharply to the east.

A newly opened up ore deposit is that of Leveäniemi. It is of large extent, but throughout its whole length is covered with from 10 to 48 feet of over-burden. Diamond drills have shown large deposits of hæmatite and magnetite. The iron contents varies from 60·73 to 70·39 per cent., that of phosphorus from 0·008 to 2·35, and that of sulphur from 0·03 to 0·05. An average sample contains 0·07 per cent. of titanic acid. The length of the deposit is estimated at over 3900 feet, and its width at from 500 to 1640 feet.

To the south-east and north-west of the village of Svappavara lie other deposits. One of these, that of Mertainen, is of very considerable extent. Thirty-seven analyses of the separated ore showed from 41·28 to 69·48 per cent. of iron, and from 0·002 to 0·277 per cent. of phosphorus. About five miles south of the above field is that of Painirova. The conditions are much the same in both cases, except that in the latter there are very considerable local enrichments of apatite, whereas in the Mertainen deposit this mineral was of minor importance. In a number of average samples the iron contents was found to vary from 51·44 to 68·31, and that of phosphorus from 0·023 to 1·587.

Owing to a thick over-burden of earth, it was not possible to thoroughly investigate this deposit. The ores may be considered as consisting of a fine-grained magnetite, which in places is very porous, probably due to one or other of the mineral constituents of the ore having been dissolved out. The percentage of phosphorus is low in the north-western portion of the district, varying from 0·014 per cent. to 0·061, with an iron percentage of from 60·69 to 69·31 in five samples examined. In the south-western and eastern portions of this field the phosphorus contents is, on the other hand, very high. It varies there from 0·244 to 1·380. The percentage of iron varies greatly, but does not fall below 50. The apatite is in part very coarse grained and unevenly distributed. The quantity of available ore is not believed to be very great.

The Ylipäsnjaska and Nokutusvara deposits are next briefly referred to, but little definite being known about them yet. The Tuolluvara deposit is about three miles to the east of that of Luossavara. Magnetic investigations point to there being two bodies of ore here, one about 650 feet, and the other some 1300 feet in length. The breadth is about 60 feet. The ore is a very fine-grained magnetite, containing small isolated quantities of other ores. Analyses showed in ten samples from 64·84 to 71·04 per cent. of iron, and from 0·002 to 0·030 per cent. of phosphorus. One sample showed 0·04 per cent. of sulphur, and another 0·53 per cent. of titanic acid.

Other deposits which are briefly mentioned are those of Rakkurijoki and Nakerivara. These are both near the Ofoten railway, but have as yet been very little investigated. A sample of ore from the former showed 42·31 per cent. of iron, 0·250 of phosphorus, and 0·21 of titanic acid. The Nakerivara ore is a fine-grained black ore partially mixed with granules of pyroxene and apatite. An analysis of ore seen to contain apatite showed 59·84 per cent. of iron and 0·251 per cent. of phosphorus; whilst ore that was apparently free from apatite showed 65·94 per cent. of iron, 0·030 per cent. of phosphorus, and 0·16 per cent. of titanic acid. A general sample taken by C. Ericsson showed 68 per cent. of iron and 0·02 of phosphorus.

Svenonius states that not far from the railway, and on the south side of the Lankkujärvi lake, is the Pidjastjåkko mountain, which rises to a height of 3330 feet. Older statements were to the effect that there was a continuous body of iron ore from the base to the summit, but this has now been shown to be not altogether accurate, there being no ore on the upper portion of the mountain. Two neighbouring ore deposits are so intimately connected with this one that the three are considered together. Syenite, granite, and greenstone form the country rock. The ore is in part magnetite and in part hæmatite. Assays of the former showed from 59·02 to 63·95 per cent. of iron and from 1·080 to 2·556 per cent. of phosphorus, while the latter contained from 47·80 to 66·90 per cent. of iron and from 0·264 to 2·062 per cent. of phosphorus. The total area of this ore field is estimated at 49,560 square metres, say 12 acres. The dip of the ore body is considerable, and it is believed that a large quantity of ore exists in this deposit. A number of other deposits are also briefly mentioned. Nearly 180 assay results are given. In these the percentage of iron is shown to vary from 37·76 to 71·04; that of phosphorus, from 0·002 to 5·665; of sulphur, from 0·007 to 0·060; of titanic acid, to a maximum of 2·60; and of calcium carbonate, up to a maximum of 33·59.

The report by W. Petersson and F. Svenonius on the minor ore deposits of Northern Sweden is discussed by O. Vogel,* and various translations of it have appeared.†

Iron Ore in Switzerland.—A brief reference is made to the iron ores of the Bernese Oberland. These were worked down to the end of the eighteenth century. The ore is found in beds of about 1 yard to 4 yards in thickness. They formerly served blast-furnaces at Mühlithal and Grund, near Innertkirchen. The fuel used was charcoal, and the woods being destroyed, the furnaces had to stop. The ore averages about 50 per cent. of iron.‡

Iron Ore in New South Wales.—W. S. Dun § has published a list of papers and reports dealing with the economic geology of New South Wales. The list includes, under a separate heading, the titles of the more important papers dealing with the occurrence of iron ore in New South Wales.

J. B. Jaquet ‖ gives some notes on the iron ore deposits in the Carcour district, Bathurst county, New South Wales. The ore is hæmatite, and analyses show as follows:—

Metallic Iron.	Silica.	Phosphoric Acid.
55·80	7·45	0·396
57·54	5·90	0·166
55·80	6·95	0·063

Iron Ore in New Zealand.—H. P. Washbourn ¶ shortly describes the Parapara iron ore deposit in New Zealand. It is situated on Golden Bay, five miles south of Collingwood. The ore is limonite, containing 53·38 per cent. of iron, and is free from phosphorus. It is found in a limestone basin, some four miles long by three broad, dipping to the north. The width of ore outcropping on the surface is from 10 to 13 chains, and shows in large masses for several miles southwards or inland. The limestone of the basin is a very pure carbonate of lime; the impurities amount at most to less than 2 per cent. Coal is being worked in a seam 4⅝ feet in thickness at the northern end of the bay.

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* *Stahl und Eisen*, vol. xx. pp. 530–536, 590–592.

† *Iron and Coal Trades Review*, vol. lxi. pp. 78, 123; *Glückauf*, vol. xxxvi. pp. 620–621, 658–660.

‡ *Stahl und Eisen*, vol. xx. p. 500.

§ *Records of the Geological Survey of New South Wales*, vol. vi. pp. 183–357.

‖ *Colliery Guardian*, vol. lxxx. p. 553.

¶ *New Zealand Mines Record*, March 1900; *Engineering and Mining Journal*, vol. lxix. p. 588.

Iron Ore in Canada.—G. B. Cowlam[*] describes the ore deposit in the county of Antigonish, in the north-east of Nova Scotia. Several large veins have been found containing hæmatite, with 49 to 65 per cent. of iron and 0·212 to 0·530 per cent. of phosphorus.

A. P. Low[†] gives a general account of the iron ores in the Labrador peninsula, and a map and some photographic views of their occurrence. As long ago as 1877, R. Bell mentioned the thick beds of siliceous spathic ore extending over 100 miles on the Nastapoka Islands, on the east coast of Hudson Bay. In 1893 the author found similar beds on the Kaniapiskau branch of the Ungava river, and later a southern extension was found on the Hamilton river. A thick bed of magnetite was found on the headwaters of the Manicoungan river. The central area extends across the Larch branch of the Ungava river and on the west coast of Ungava Bay. Beds of magnetite-hæmatite were found under the spathic ores of Nastapoka Islands. The central area is the largest and covers about 15,000 square miles. Two analyses show:—

FeO.	Fe_2O_3.	MnO.	Insoluble.
21·32	23·43	1·34	6·72
0·35	80·17	3·09	13·78

William M. Brewer[‡] describes the iron ore deposits of Vancouver and Texada islands, British Columbia. They are rich deposits which have received little attention.

Iron Ore in Newfoundland.—W. Scott[§] gives some notes on the mineral deposits of Newfoundland, and includes some illustrations of the iron ore mines on Belle Island, Conception Bay.

H. B. C. Nitze[‖] describes the Wabana iron ore mines. The deposits are mined by open quarries, and are situated close to deep-water shipping facilities.

W. R. Nursey[¶] gives some notes on the iron ore resources of Canada and Newfoundland. On Belle Island, in Conception Bay, there are two main beds, 200 feet apart, and dipping 6° to 8°. The length of the lower bed outcrop on the land is 3¾ miles, and it is 5 feet in thickness, while the upper outcrop is 1½ miles, but it has not yet been touched. From the three workings in the lower bed the ore obtained shows 56 to 60 per cent. of iron with 0·4 to 0·7 of phosphorus. Other districts are also described and illustrated.

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[*] *Iron and Coal Trades Review*, vol. lxi. pp. 116–117; *Colliery Guardian*, vol. lxxx. p. 136.

[†] *Engineering Magazine*, vol. xix. pp. 205–210.

[‡] *Engineering and Mining Journal*, vol. lxix. p. 526.

[§] *Ibid.*, vol. lxx. pp. 155–156.

[‖] *Mines and Minerals*, vol. xx. pp. 413–414.

[¶] *Iron and Coal Trades Review*, vol. lx. p. 1065.

The Crystal Falls Iron-bearing District.—The United States Geological Survey * has published a monograph, covering 512 pages, with 53 plates and 24 illustrations, on the Crystal Falls iron-bearing district of Michigan, by J. M. Clements and H. L. Smyth, with a chapter on the Sturgeon river by W. S. Bayley and an introduction by C. R. Van Hise. The district derives its name from the principal mining town, and the area reported upon connects the Marquette district on the north and the Menominee district on the south. The ore worked is hæmatite and limonite, associated with white and reddish chert. The ore bodies, which dip to the west at varying angles, are concentrates in synclinal troughs. The mining is now for the most part underground, and is carried on in open stopes. The greatest shipment of ore from the area was 586,970 tons in 1892. The district embraced in the report covers 1296 square miles, including the Crystal Falls, Amasa, Felch mountain or Metropolitan and Sturgeon river districts. Of these, the first two produced nearly 325,814 tons of ore in 1898, chiefly non-Bessemer hæmatites and limonites. Geologically the district connects the Marquette and Menominee districts, and consists of Huronian rocks enclosing two archean patches. The history of the Crystal Falls district is closely parallel to that of the Marquette district, but the number of distinct formations recognised in it is smaller. The ores exist in it in Huronian beds, which lie unconformably above an older series of crystalline schists. Glauconite or some iron carbonate was the original source of the iron, and descending waters were the agents of decomposition, transportation, and precipitation.

Iron Ore in Georgia.—R. H. Couper † notes the increasing importance of the yellow-ochre mines of the Carterville district in Georgia. The bed is 3 to 8 feet in thickness and about 28 tons of ochre are produced daily.

Iron Ore in Massachusetts.—In a monograph on the geology of Eastern Berkshire, Massachusetts, B. K. Emerson ‡ points out that there is not the slightest possibility of finding coal in the district. Much money has, however, been wasted in fruitless search. Mining for iron ore has been encouraged by the rusty nature of the pre-Cambrian rocks, especially in the upper strata. As this rustiness depends largely upon the decomposition of iron pyrites, it is not a good indication of valuable ore.

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* *Monographs of the United States Geological Survey*, vol. xxxvi.

† *Engineering and Mining Journal*, vol. lxix. p. 738.

‡ *United States Geological Survey*, Bulletin No. 159.

Iron Ore in Washington.—G. O. Smith * and B. Willis describe the Clealum iron ore deposits in the eastern spurs of the Cascade Range, Washington. The ore occurs in two lines of outcrop, in lenses varying up to 30 feet in thickness, over serpentine and under the Swank limestone. The iron contents range from 35 to 59 per cent. according to its richness. It contains both hæmatite and magnetite, and may be enriched by hand-picking. The geology of the ore and of the district, and the question of the origin of the deposits, are discussed. W. M. Courtes adds some further analyses of the ore.

The Titaniferous Iron Ores of the Adirondacks.—In an exhaustive memoir, illustrated by nine plates, J. F. Kemp † gives a detailed description of several bodies of magnetic ore, developed by the gradual enrichment of a normal gabbro containing labradorite pyroxene, olivine, and magnetite. The deposits described have been discovered in the Adirondacks in Essex county. Details of all the deposits are given, and the author also discusses the chemical composition of titaniferous magnetite, and of ilmenite considered as minerals, the chemical composition of the titaniferous iron ores, the geographical distribution of the titaniferous iron ores in the Adirondacks, the geological formations associated with the ores, and the mode of origin of the ores. The memoir concludes with a review of titaniferous ore elsewhere in the United States and in other countries.

Iron Ore in China.—J. G. H. Glass ‡ describes the coalfields and iron ore deposits of the provinces of Shansi and Honan in China, and the proposed railway connections.

Captain Bernard, § who is engaged in surveying for the proposed railway from Tourane to Hué, in Indo-China, has discovered on the Hué river a deposit of iron ore, a sample of which yielded on analysis 91·8 per cent. of ferric oxide, 1·6 per cent. of alumina, 6 per cent. of silica, and 0·6 per cent. of water.

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* *Transactions of the American Institute of Mining Engineers*, Washington meeting, 1900.

† *United States Geological Survey, Nineteenth Annual Report*, Part iii. pp. 377–422.

‡ Paper read before the British Association, 1900.

§ *Echo des Mines*, vol. xxvii. p. 1063.

Recent Researches on Meteorites.—S. Meunier* gives an account of the meteorite, weighing about 750 lbs., which fell on March 12, 1897, in the Gulf of Finland, making a hole 9 yards in diameter through ice 26 inches in thickness, and burying itself 6 yards deep in the submarine clay. Two pieces of 184 and 48 lbs. were exhibited at the Paris Exhibition. The author describes it as oolitic, composed of chrysolite and pyroxene, with grains of nickel iron, iron sulphide, and chromite. Its specific gravity is 3·54.

According to H. L. Preston,† a meteoric iron, which weighs 6903 grammes, was found in 1896 near Luis Lopez, Socorro Co. It contains numerous nodules of troilite surrounded by zones of schreibersite or of a graphitic substance. The etched surface shows typical octahedral Widmanstätten figures. The structure and chemical composition (analysis I.) of this iron distinguish it from the five other irons (Costilla, Glorieta, El Capitan, Sacramento Mountains, and Oscuro) recently found in the same region in New Mexico.

	Fe.	Ni.	Co.	Si.	P.	S.	C.	Totals.	Sp. gr.
I. . .	91·312	8·170	0·160	trace	0·333	0·013	0·012	100·00	7·7
II. . .	94·734	4·620	0·180	...	0·442	0·015	0·009	100·00	7·5

All that is known of the history of the Central Missouri iron is that it was found in the fifties in Central Missouri. About half the mass weighs 12,360 grammes. It is penetrated by numerous fissures filled with a graphite-like substance, and in part by schreibersite. The etched surface is minutely pitted. Analysis gave the result shown under II.

W. E. Hidden ‡ illustrates a piece of meteoric iron found in Hayden Creek, Idaho, by a gold prospector at the bottom of a twelve-foot shaft. With much difficulty he succeeded in breaking it with a 14-lb. sledge.

H. L. Preston § describes an aërolite from Oakley, Logan County, Kansas, weighing 61 lbs. 10 oz. It contains 14·44 per cent. of iron and nickel in the metallic state and 85·56 per cent. of silicates. It is of the chrondritic olivine-enstatite type.

E. Boscá y Casanoves ‖ describes the meteorite that fell at Quesa, in Valencia, Spain, on August 1, 1898. It weighs 10,670 grammes, and has the fine-grained structure of an ataxite. Its specific gravity is

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* *Le Naturaliste; American Journal of Science*, vol. x. p. 250.

† *American Journal of Science*, vol. ix. pp. 283–286.

‡ *Ibid.*, vol. ix. pp. 367–368.

§ *Ibid.*, pp. 410–412.

‖ *Actas Sociedad Española Hist. Nat.*, 1899, pp. 53–56; *Journal of the Chemical Society*, vol. lxxviii. p. 415.

6·48. Analyses of the oxidised outer portion (I.), and of the interior of the mass (II.) gave the following results :—

	Fe.	Ni.	Co. Mn. &c.	O.	Totals.
I. . . .	79·07	17·95	traces	2·98	100·00
II. . . .	81·35	18·35	0·30	...	100·00

Emil W. Cohen[*] gives some details of a new examination of a larger piece of the meteoric iron from Quesa, Spain, which shows the structure to be octahedral with lamellæ of medium width. A new analysis (I.), which has been made since the previous analysis by Peset, shows much more nickel than any other known octahedrite. The previous determination of the fine-grained structure was based on the examination of small fragments from the external part of the mass; this is much poorer in nickel (analysis II.) than the interior.

	Fe.	Ni+Co.	P.	Totals.
I. . . .	88·73	10·85	0·15	99·73
II. . . .	95·56	4·40	...	99·96

According to E. Artini and G. Melzi,[†] a meteorite fell in July 1889 at Ergheo, near Brava, in the Somali peninsula; it weighs 20,375 grammes, but was originally somewhat larger. Its specific gravity is 3·31. Chondrules of olivine or of enstatite, or of both, are set in a crystalline ground mass of olivine and enstatite; troilite, metallic nickel iron, magnetite, glass, maskelynite, and possibly felspar, are also present. Analysis gave the following results :—

Metallic Fe.	Ni+Co.	FeS.	Sol. in HCl.	Insol. in HCl.	Total.
0·57	0·17	9·48	56·50	32·73	99·45

	SiO_2.	FeO.	Al_2O_3.	CaO.	MgO.	Na_2O. K_2O.	Totals.
Sol. in HCl.	23·69	12·95	0·56	0·71	18·59		56·50
Insol. in HCl.	57·62	12·79	5·11	1·13	23·06	0·41	100·12

Emil W. Cohen[‡] states that the meteoric iron from Morradal, Norway, was found at Morradal, near Grjotli, between Skiaker and Stryn; it weighs 2750 grammes. It belongs to the group of ataxites rich in nickel. Analysis gave the following :—

Fe.	Ni.	Co.	Cu.	Cr.	P.	S.	Sp. gr.
79·67	18·77	1·18	0·06	0·06	0·18	0·27	7·8543

This corresponds with the following mineralogical composition—nickel iron, 98·12; schreibersite, 1·17; troilite, 0·55; and daubreelite, 0·16 per cent.

[*] *Mittheilungen des naturwissenschaftlichen Vereins für Neu-Vorpommern und Rügen*, Berlin, vol. xxxi. pp. 63–66.

[†] *Jahrbuch für Mineralogie*, 1900, i. Ref. 357–360; *Società d'Esplorazione Commerciale in Africa*, Milan; and *Rend. R. Ist., Lombardo*, vol. xxxi. pp. 983–994.

[‡] *Jahrbuch für Mineralogie*, 1900, i. Ref. 354; *Videnskabs-Selskabets Skriften*, 1900.

Emil W. Cohen * gives some new analyses of the following meteoric irons:—

Salt River, Kentucky.—In structure (octahedral with fine lamellæ) and composition (analysis I.) this resembles the Ballinoo and Tocavita irons. Specific gravity, 7·6648.

Cape of Good Hope.—Analysis II. Specific gravity, 7·8543. This resembles the Kokomo and Iquique irons.

Babb's Mill, Green County, Tennessee.—Analyses III. and IV. are of material from different portions of the mass described by Blake in 1886 under the name Green County. V. is of the Babb's Mill mass, described by Troost in 1845. Although these differ considerably in chemical composition, they probably represent the same fall, since both belong to the rare type of ataxites rich in nickel.

	Fe.	Ni.	Co.	Cu.	Cr.	C.	S.	P.	Cl.	Totals.
I. . .	90·89	8·70	0·85	0·04	0·00	0·02	trace	0·34	...	100·84
II. . .	82·87	15·67	0·95	0·03	0·04	0·03	0·00	0·09	0·01	99·69
III. . .	88·41	11·09	0·66	undet.	0·02	0·03	trace?	trace	0·02	100·23
IV. . .	88·23	11·01	0·72	undet.	0·02	0·03	trace?	trace	0·01	100·02
V. . .	81·45	17·30	1·67	0·03	0·03	0·07	0·01	0·12	undet.	100·68

Origin of Native Iron.—C. Winkler † suggests that the native iron found in the basalt of Disko Island, West Greenland, may have been formed from iron and nickel carbonyls.

Manganese Ore in France.—F. Klockmann ‡ describes the manganese ore deposits of the French Pyrenees. The deposits are of two types:—1. Those of the Vielle Aure type, which are conformably interstratified between Devonian slates. The ore consists of manganese oxides that pass with increasing depth into silicates (rhodonite and friedelite). 2. Those of the Las Cabesses type, which occur in Upper Devonian grits. The outcrop consists of oxides, but at greater depths masses of pure carbonate occur. In a crude state the ores contain 40 to 42 per cent. of manganese, 1·5 to 2 per cent. of iron, 6 per cent. of lime, 6 to 7 per cent. of silica, and 0·04 to 0·05 per cent. of phosphorus. When calcined, the ores contain 50 to 56 per cent. of manganese.

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* *Annalen des k.k. naturhistorischen Hofmuseums zu Wien*, vol. xv. pp. 74–94; *Journal of the Chemical Society*, vol. lxxviii. p. 664.

† *Berichte der königlichen sächsischen Gesellschaft, Mathematische-physikalische Klasse*, vol. lii. pp. 9–16; *Journal of the Chemical Society*, vol. lxxviii. p. 598.

‡ *Zeitschrift für praktische Geologie*, 1900, pp. 265–275.

Manganese Ore in the Caucasus.—The British Consul at Batoum devotes a section of his latest report [*] to the manganese ore industry of that district, which, on account of the increased demand in the European and American markets, has grown very much of late. In 1899 the exports from Batoum and Poti amounted to 416,340 tons, against 282,316 in 1898. The industry has now assumed very large proportions, but a still greater development is likely to take place, as a demand for the ore abroad is increasing; besides which, Russia is also annually becoming a larger consumer. But the industry is still suffering from primitive methods at the mines, difficulties in the transport of the ore from the mines to the railway station, lack of rolling stock along the narrow-gauge section of the railway to the trunk line, the exceedingly high rate of transport charged by the railway, and loss of time at Poti.

Manganese Ore in the United States.—A. A. Wheeler [†] deals with the American consumption and supply of manganese ore, referring the tonnage to a common standard of 50 per cent. ore.

Chromite in North Carolina.—According to J. H. Pratt, [‡] the existence of large deposits of chromite in North Carolina has not been conclusively shown, but the work done, however, points to the probability of large deposits in that State. The most promising ones known are described. Several of them have yielded ore containing over 50 per cent. of chromium sesquioxide, and quantities of ores up to 50 or more tons have been taken out of some of the pockets.

II.—*IRON ORE MINING.*

Steam-Shovels.—W. Fawcett [§] describes the use of steam-shovels in the mines of the Lake Superior district and in other places, such as at the docks for handling ore. Some particulars of their dimensions, and of the work they can do, are given, and the Thew steam-shovel is described, with the aid of an illustration.

Excavating Machine.—An illustration is given [||] of an excavating and loading machine used in an iron mine at Fayal, Minnesota, for loading ore into waggons. The machine is the first one built, and it has worked well, except that parts require strengthening. It consists of a kind of bucket elevator, like that used in a dredge, mounted on a truck with a pivoted adjustment, the angle of which can be altered. It excavates and raises the ore so that it falls into the waggons.

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[*] Foreign Office Report, August 1900.

[†] *The Mineral Industry*, vol. viii. pp. 420–428.

[‡] *Engineering and Mining Journal*, vol. lxx. p. 190.

[§] *Iron Age*, May 10, 1900, pp. 1–2.

[||] *Iron and Coal Trades Review*, vol. lxi. p. 676; *Engineering News*, vol. xliv. p. 200.

Construction of a Dam.—W. Oppl* describes the construction of a dam to keep back water issuing from a long cross-cut in connection with the Przibram mines in Bohemia. In its construction 48 tons of Portland cement, 26 tons of slag sand, 5000 slag bricks, and other material was employed. The total cost of the materials was about £31, and the wages paid amounted to about £83. Details are given as to how a spot was selected at which to construct the dam, and then of the dam itself. The central portion of this consisted of a mixture of one part of Königshof Portland cement and two parts of granulated iron blast-furnace sand and four parts of quartz. This was prepared quite close to the dam. The great care taken in the construction of the dam, and the difficulties that had to be overcome in its construction, caused this to require about ten weeks for its completion. It had to withstand great pressure, and this was subsequently found by a manometer to have reached thirty-one atmospheres, at which the pressure has remained constant since August 1898, the dam having shown no signs of yielding. It was, however, anticipated that the dam would have to withstand a still higher pressure, estimated at as much as forty-one atmospheres. The erection of this dam has meant a saving of about 40 tons of coal a month for pumping purposes.

Iron Ore Mining in Belle Island.—R. E. Chambers † gives some notes on the iron ore mining at the Wabana mine on Belle Island, with numerous plans and illustrations, especially of the haulage, storage, and shipping plant.

Lake Superior Mining.—According to W. Fawcett,‡ activity in the Lake Superior iron ore district has greatly increased this year, and a recent estimate places the ore in sight at 400,000,000 tons. At the Riverton mines, on the Menominee Range, the Iron river, a stream of considerable size, has been diverted.

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* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. pp. 33-36, with three illustrations.

† *Journal of the Canadian Mining Institute*, vol. iii. pp. 130-132, with six plates.

‡ *American Manufacturer*, vol. lxvi. pp. 274-275.

The fiftieth anniversary of the organisation of the Cleveland Iron Ore Company was made the occasion for some reminiscences of the early days of Lake Superior iron ore mining.[*] A sketch showing the open-cast in 1869 is reproduced among other illustrations.

Ore Mining at the Pewabic Mine.—N. P. Hulst[†] gives the method devised by E. F. Brown for mining the ore at the Pewabic mine on the Menominee Range by the caving system. The ore is divided into blocks 250 feet long between the levels, which are 100 feet apart. The main level is driven in the hanging wall slates, 20 feet from the ore body, and cross-cuts are put through to the foot-wall. Rises 50 feet apart are put up for a distance of 80 feet, and then practically all the ore is worked out on the lower side, leaving two strong pillars alongside the main cross-cut on the end of the block, and small irregular pillars to support the main body of the ore. These are blasted out, and gradually the whole body of the ore settles, and breaks up to such an extent that it flows easily into the drifts and cross-cuts, whence it is trammed away.

The Tilly-Foster Mine.—According to E. K. Landis,[‡] the Tilly-Foster mine in New York is a deposit similar to the New Jersey and Lake Champlain magnetites. At first it was worked by an incline in the foot-wall, with levels every 100 feet, from which rooms 24 feet wide, leaving 20 feet pillars, were worked across to the hanging wall, and then carried up nearly to the level above. Masonry pillars were built into some of the rooms with a view of removing the ore pillars, but without success, and finally the roof was removed and the ore worked open-cast. Between 1879 and 1899, 951,957 tons of ore and concentrates have been shipped, and of this amount 616,898 tons were obtained in the latter form. The ore is now stripped to a depth of 430 feet, and 250,000 to 300,000 tons of ore are available. The excavation is measured by a plumb bob and tape, dropped from a trolley running on a rope stretched across the pit, which is divided up into 10-foot squares.

Handling Iron Ore.—A most valuable and fully illustrated account of the various methods of handling ore and coke is published by Frahm.* The account is one of very considerable length, and generally is a most important addition to the literature of this subject.

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[*] *Iron Trade Review*, July 19, 1900, pp. 16–19.

[†] *Proceedings of the Engineers' Society of Western Pennsylvania*, vol. xv. pp. 62–104.

[‡] *Journal of the Franklin Institute*, vol. cl. pp. 223–226.

In a series of articles, the questions connected with the transport and storage of iron ore and coal are dealt with very fully by M. Buhle.† The author gives a large number of illustrations descriptive of the methods in use for the above purposes at a large number of different places.

Aumund ‡ describes the Hunt transporters for iron ore erected at several European works.

A. Hausing § discusses the relative value of wire ropeways. In the case in question, the ore had to be brought down to a washing plant from a mine nearly 1100 feet higher up. The old system of waggons, cars, or sledges did not succeed in keeping the washing plant fully employed, and besides was very costly. A new method had therefore to be adopted. The question considered was whether this should take the form of an incline or of a wire ropeway. The cost of the former was less than two-fifths that of the latter, and it was consequently erected. It worked very well in summer, but cost far too much to keep open in winter, as six feet or more of snow often settled upon it. A wire ropeway was subsequently erected elsewhere at these mines. This was more expensive to build, but requires less labour, and is generally much cheaper to work, besides not suffering from winter snow.

A. Dory ‖ describes and illustrates the cantilever loading stages of Onton, Dicido, Sonavia, Castro-Allen, Castro-Urdiales, and Setares on the northern coast of Spain, in Biscay, Guipuzcoa, and Santander. That at Onton is the largest, being 328 feet in length, with an overhang of 213½ feet, and a height of 55 feet above sea-level.

W. Fawcett ¶ illustrates and describes the three Hulett ore unloaders at Conneaut, Ohio, on Lake Erie, one of which was in work last year, and the two new machines, which are practically double machines. In the first machine a clam-shell bucket, holding 10 tons, is carried by a leg at the end of a pivoted beam, and the leg is kept vertical by a parallel motion. The beam is tilted to raise or lower the bucket, and is mounted on a truck, which runs on staging at right angles to the dock, so that the bucket, when filled, is brought inland to discharge over a hopper. The staging itself is mounted on rails to run parallel with the wharf. In the new machines the bucket and beam, &c., are in duplicate, but one is lighter than the other, and they are spaced so as to work on two holds simultaneously. The lighter bucket follows the other, so as to clear the hold after the heavier bucket has taken out the bulk of the ore.

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* *Stahl und Eisen*, vol. xx. pp. 513-522, 597-603, 653-661, 698-701, 750-752, and 798-802, with 70 illustrations.

† *Zeitschrift des Vereines deutscher Ingenieure*, vol. xxxiv. pp. 725-732, 1093-1098, with 220 illustrations.

‡ *Stahl und Eisen*, vol. xx. pp. 825-835; *Colliery Guardian*, vol. lxxx. pp. 475-478.

§ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. p. 442.

‖ Pamphlet presented to the Library by the Author.

¶ *Iron Age*, April 5, 1900, pp. 1-5.

A. C. Johnston * describes, with numerous illustrations, the dock equipment for rapid handling of ore and coal on the great American lakes. The construction of the docks and quays, and of the M'Myler and Hulett unloading machines, and of the Brown King and other ore hoists, are dealt with in some detail.

D. E. Woodbridge † gives particulars of the eastern Minnesota ore dock on Lake Superior. Its height above water-line is 73 feet, an increase of 14 feet over previous designs, and the width has been increased from 49 to 62·8 feet. Its capacity is 65,000 tons. A number of illustrations are given to show the construction, and a list of the other docks is appended.

III.—*MECHANICAL PREPARATION.*

Magnetic Concentration.—At the International Congress on Mining and Metallurgy held in 1900 in Paris, H. Wedding discussed the magnetic separation of iron ores. Iron ores obtained by mechanical preparation are nearly always unutilised, because they are produced in a state of fine grains, which could not be treated in the blast-furnace in any large quantities. This was why the purple ore, one of the purest of minerals, could very rarely be used. All the iron ores, with the exception of magnetites, which were, of course, strongly magnetic, were magnetic in a small degree, and this was the case even with pyrites, which for a long time had been regarded as diamagnetic. The various systems of mechanical separation, including the Edison and the Wetherill processes, are described. If the grains of mineral were to be thoroughly separated, it was necessary that they should be pure, and in order to know the size of the grains to which the mineral should be reduced for treatment, it was advisable to examine them with a microscope. In treating ores mixed with pyrites, it was possible to obtain good results by, first of all, partially roasting the ore, so as to eliminate the sulphur, and a large number of minerals, which could only be separated with difficulty by the magnet when dry, could be easily treated when they were held in suspension in water. There is a vast field open for good and useful inventions for the magnetic separation of minerals, and there is also a great deal to be done in utilising the very fine ore obtained by these processes in the blast-furnace without considerably diminishing the production or augmenting the cost of fuel. The only satisfactory solution seems to be to transform the fine ore into compact masses, and it has been proposed to manufacture briquettes by means of a mixture of argillaceous cement; but the result has not been satisfactory any more than the other methods of using hydrated lime and siliceous matters. Trials with a mixture of very fine grains of iron ore and coal had failed, but with certain other bodies containing carbon, such as tar and petroleum or cellulose by-products, some success has been attained by raising the materials to a relatively high temperature and subjecting them to a great pressure. A solid product could only be obtained with very fine grains of mineral, so that in this sense the magnetic preparation gave the best results. These trials were still incomplete, and required to be followed up on a larger scale.

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* *Transactions of the Institution of Mining Engineers*, vol. xix. pp. 82–104; *Journal of the Association of Engineering Societies*, vol. xxiv. p. 1; *Cassier's Magazine*, vol. xviii. pp. 355–372.

† *Iron Age*, June 21, 1900, pp. 11–13; *Engineering News*, vol. xliv. p. 189.

A further paper by Smits also describes the Wetherill process and the Lohmannsfeld plant, erected in the Siegen district for treating a mixed ore containing blende, galena, spathic iron, &c.

The Wetherill process is described by C. Blömeke * in an article on the progress of ore dressing, of which a translation has appeared.†

N. Pellati ‡ describes the mechanical and other appliances used in Sardinia for dressing ores. Magnetic separators are used for limonite, rendered magnetic by roasting.

E. Ferraris § describes some ore-washing plants in use at the mines of Sardinia. Some "swinging sieves" are described as used for various ore sizes. Mention is also made of a small plant for the magnetic

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* *Berg- und Hüttenmännisches Jahrbuch der k.k. Bergakademien*, vol. xlvi.

† *School of Mines Quarterly*, vol. xxi. pp. 28–47, 136–169, 239–260.

‡ Paris Congress on Mining and Metallurgy, 1900 (advance proof).

§ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. pp. 229–231; with illustrations.

separation of iron and zinc ores in use at Monteponi. This has a capacity of about a ton an hour.

E. Langguth [*] discusses the principles underlying the magnetic separation and concentration of minerals, and describes experiments he made, in which the ratios between motion and magnetism were altered.

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[*] *Zeitschrift für Electrochemie*, vol. vi. pp. 500–506.

REFRACTORY MATERIALS.

Fireclay.—H. Seger * and E. Cramer give analyses of the raw and burnt clay from Breitscheid, Germany. Clay I. has a melting-point about equal to the Seger cone No. 34, while the melting-point of clay II. lies between those of the Seger cones Nos. 32 and 31.

	I.		II.	
	Raw.	Burnt.	Raw.	Burnt.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Loss on ignition	14·54	...	15·48	...
Silica	45·74	53·49	53·78	63·63
Alumina	37·84	44·25	28·89	34·18
Ferric oxide	1·08	1·26	1·08	1·28
Lime	trace	trace	trace	trace
Magnesia	nil	nil	nil	nil
Alkalies	0·92	1·07	0·84	0·98
Total	100·12	100·07	100·07	100·07

This clay was known and used in the Middle Ages.

H. Wedding † gives the following analysis of a kaolin from Mituiski, in Japan, which is used in the manufacture of the bricks employed in the chequer-work of the regenerators of open-hearths :—

	Per Cent.
Silica	61·72
Alumina	36·67
Ferric oxide	0·63
Magnesia	0·29
Potash	0·98
Soda	0·10
Total	100·39

It has a very high melting-point, about that of the Seger cone No. 35. In manufacturing the bricks, 12 per cent. of pure burnt kaolin is mixed with unburnt clay. Of this a mixture is made of coarse and fine material obtained by separation by sifting. In this way bricks can be made that have a fine-grained surface, and do not hold the dust.

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* *Stahl und Eisen*, vol. xx. p. 500.

† *Ibid.*, p. 779.

Firebricks.—Full analyses are given* of a number of German and other firebricks, together with their relative fire-resistance, specific gravity, water absorption capacity, and contraction or expansion on heating. The German bricks are shown to be the best.

In a paper read by Hecht † before the *Verein Deutscher Fabriken Feuerfester Producte*, analyses are given of a number of firebricks met with in commerce. Non-German firebricks were found to contain :—

SiO_2.	Al_2O_3.	Fe_2O_3.	$CaO+MgO$.	Alkalies.
54·5–64·3	30·5–40·5	1·6–6·0	1·0	1·5–3·9

German firebricks were found to contain :—

SiO_2.	Al_2O_3.	Fe_2O_3.	$CaO+MgO$.	Alkalies.
51·1–50·0	45·7–46·2	0·8–1·6	...	0·3–1·2

The foreign bricks showed almost always a large degree of expansion and contraction on heating and cooling, while the German bricks submitted to examination only slightly altered their volume. The melting-points of the non-German bricks varied from Nos. 28 to 34 of the Seger scale, while the German bricks had a much higher melting-point. Some of these nearly reached No. 36 of the scale.

Sand for Furnace Bottoms.—C. Ferry ‡ discusses the nature of sand used for rolling-mill reheating furnaces. These sands should set within fifteen minutes in the furnace to form a hard durable bottom; but they must not contain clay, nor be of a loamy nature, or they stick to the iron. The setting property is not dependent on the chemical composition only; the size of the grain has considerable effect. Coarse sand requires more heat than fine sand. In the following analyses of sand, the first was in regular use, but the second refused to crust over or set :—

SiO_2.	$Al_2O_3+Fe_2O_3$.	CaO.	MgO.	H_2O.
91·55	7·40	0·51	0·11	0·61
91·47	4·88	0·21	...	3·61

If chemical analysis is used as a guide, the results should be considered as follows: (1) combined silica, alumina, quartz, *i.e.* refractory constituents; (2) combined water, *i.e.* refractory property; (3) lime, magnesia, ferric oxide, fixed alkalies, *i.e.* fluxes. The size of grain should also be observed. Sand having plasticity should be avoided. It should be short, sharp, and clean. Combined water indicates the presence of kaolinite, and should therefore be low. The fluxes probably range from 4 to 5 per cent., but vary in amount according to the nature of the constituents, as the alkalies are more powerful fluxes than iron.

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* *Stahl und Eisen*, vol. xx. pp. 640–643.

† *Chemiker Zeitung*, vol. xxiv. p. 192; *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii.; *Beilage*, pp. 38–39.

‡ *The Mineral Industry*, vol. viii. pp. 513–514.

Graphite Crucibles.—W. F. Downs* deals with the occurrence, treatment, and application of graphite. The total annual production is not exactly ascertainable, but it certainly does not exceed 60,000 tons yearly. Austria and Ceylon are the leading producers, and a fair quantity is also obtained in Germany and Italy. The raw material is difficult to treat owing to the close approximation of the gangue to the graphite in its specific gravity. Both wet and dry methods are, however, in use. The manufacture of crucibles is then described on general lines, and their use is dealt with, after which the materials and mixtures used and the processes adopted are considered in greater detail.

Graphite in Bavaria.—In a report on the economical condition of Bavaria, F. D. Harford,† of the British Legation at Munich, says that graphite is one of the most valuable minerals found in Bavaria, and represents almost a monopoly for the country, as the only formidable competitor in the supply of natural graphite is Ceylon. The production in Ceylon has, however, decreased in the last six years from 30,000 tons to 12,000 to 15,000 tons annually, causing a great rise in prices, as the deficit could not be made good from other sources. The price of Ceylon graphite ranges from £50 to £75 per ton. In Bavaria the graphite deposits are found near Passau, and are inferior to the Ceylon graphite, as, while the latter is nearly pure, the former has about 60 to 75 per cent. of earthy substances mixed with it. The Passau graphite, however, can be purified by a very simple and inexpensive process, and a substance produced that is quite equal to the Ceylon graphite. Unfortunately this process is little used, as the deposits are spread amongst a number of small proprietors, who work on a small scale, in the cheapest manner possible. The result is that there is a waste of raw material, of which it is said that nearly 90 per cent. is absolutely thrown away owing to the unscientific system of working, which must lead to the premature exhaustion of the deposits. In 1898 there were forty-nine graphite works in Bavaria, employing only 216 men, which produced 4593 tons of graphite, worth £19,583.

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* *Iron Age*, April 19, 1900, p. 8; May 3, p. 3; May 10, p. 9; May 24, p. 5; June 14, p. 26.

† Foreign Office Report, September 1900.

E. Weinschenk,[*] in describing the mode of occurrence of graphite in Bavaria, observes that for centuries past the larger portion of the graphite mined has been converted at Obernzell into crucibles ("Passau crucibles"). The raw material is crushed and ground, and then subjected to sifting or blowing operations. The large-flaked graphite occurring in the gneiss is not crushed, but the other rock minerals present are ground into powder. In this simple way from low-grade stuff a graphite can be obtained which contains from 92 to 94 per cent. of carbon, and is quite free from the pyrites originally present. It is stated to be equal to Ceylon graphite for crucible manufacture. When used for this purpose, it is well mixed with clay in large puddling machines, and the mixture is subsequently formed into crucibles and burnt.

Graphite in Ceylon.—According to E. Weinschenk,[†] the more important graphite deposits of Ceylon are veins in granulite, which probably owe their origin to volcanic vapours containing carbonic oxide and cyanogen, and not to hydrocarbons. Graphite deposits, he considers, do not represent the oldest equivalent of the coal seams of the fossil-bearing formations.

According to A. K. Coomara Swamy,[‡] in the island of Ceylon graphite occurs chiefly in branching veins in igneous rocks, which at Ragedata are granulites and pyroxene granulites. The relations to the matrix are held to favour the idea of the deposition of the mineral as a sublimation product (Walther), or from the decomposition of liquid hydrocarbons.

Some photographic illustrations of graphite mining and dressing in Southern India have recently appeared.[§]

Graphite in the United States.—The production of graphite in the United States during 1899 is given as 3,632,608 lbs., or more than double the output in the previous year. The various sources of graphite are described.[||]

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[*] *Stahl und Eisen*, vol. xix. pp. 1133–1134.

[†] *Zeitschrift für praktische Geologie*, 1900, pp. 174–181.

[‡] *Quarterly Journal of the Geological Society*, vol. lvi. pp. 590–615.

[§] *Iron and Coal Trades Review*, vol. lxi. pp. 266–267.

[||] *The Mineral Industry*, vol. viii. pp. 348–352.

FUEL.

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I.—*CALORIFIC VALUE.*

Calorimetry.—C. V. Kerr [*] gives some notes on the Berthier method of determining the calorific value of coal by weighing the buttons of lead produced on fusing a mixture of litharge and the powdered fuel. In view of the fact that a different amount of heat is lost in the products for combustion from the hydrogen and the carbon in the fuel, and that allowances may be made for the bituminous or non-bituminous nature of the coal, fairly comparative results may be obtained, and of these a number are given.

Euchène [†] has presented to the International Gas Congress at Paris a lengthy paper dealing with the thermal reactions that occur during the distillation of coal. The amount of the products and the heat liberated or absorbed in their production is given for several varieties of coal and peat, the results being shown in a large number of tables.

W. Kent [‡] discusses the economical use of fuel, and summarises the recent researches on the calorific value, with special attention to the work of Lord and Haas.

E. D. Meier [§] gives a popular account of the amount of energy contained in a pound of coal, and of the amount of work it is capable of giving.

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[*] *Transactions of the American Society of Mechanical Engineers*, vol. xxi. pp. 304–316.

[†] *Journal of Gas Lighting*, October 1900.

[‡] *The Mineral Industry*, vol. viii. pp. 124–157.

[§] *Cassier's Magazine*, vol. xviii. pp. 65–70.

Pyrometry.—L. Holborn[*] and A. L. Day have continued their investigations on a gas thermometer consisting of a platinum-iridium bulb used at high temperature, and have determined its expansion and the effect on it of gas expansion. A number of melting-points up to copper at 1084° C. were determined. Some remarks are also made on measurements with thermo-elements, and the precautions to be taken when using them.

A photographic illustration of Uehling's pyrometer has appeared.[†]

II.—*COAL.*

The Chemical Classification of Coal.—C. A. Seyler[‡] reviews the attempts of various authorities to find a satisfactory system of classification for coal, and then proposes a further one based on the ultimate chemical composition. His conclusions are summarised by the author, and diagrams are given to show the range of his classes. He finds that the carbon percentage may be advantageously substituted for the combined oxygen and nitrogen of Regnault, and the total hydrogen for Fleck's disposable hydrogen. A purely chemical classification based on the percentage of carbon and hydrogen groups the coals into natural classes. There is a correlation between hydrogen and volatile matter, and also the caking power for coals rich in carbon, but for coals rich in oxygen the latter does not appear to be related to the amount of hydrogen. In each carbon class the hydrogen may range from above to below the normal, and so short, normal, and long-flame coals may occur in it. Richter's and Campredon's methods of determining the caking power, by mixing with sand, &c., before caking, is of value, and the caking power is rated as discretive, accretive, and concretive by the author. All chemical results and physical, &c., characteristics should be referred to the pure combustible after elimination of the moisture, ash, and combustible sulphur. Standard chemical methods are advisable.

F. Kotte[§] gives further[||] details as to the use of the Röntgen rays in the examination of coal. Some of the previous experiments as to how far these rays might be utilised in ascertaining the percentages of ash in coal had shown that the permeability of one and the same seam for these rays varied in different parts to such an extent as to render them useless as a guide as to the ash contents. The author concluded that while any slate mixed with the coal was relatively of an approximately good degree of permeability, small admixtures of the oxides of the heavy metals greatly reduce the permeability of the coal for these rays. The author has since investigated this point, and now publishes the results obtained. In these last experiments the author first selected some samples which were found by the Röntgen rays to be very pure, and then powdered these very fine. The powdered samples were then carefully mixed and the ash determined. This was found to be 1·66 per cent. Six different samples of slate, shale, and blackband were then powdered and passed through the same sieve, and the percentages of iron and residues after ignition determined. Six mixtures were then made of the coal samples on the one hand, and of these powdered materials on the other, in such a way that the resulting mixtures each contained 10 per cent. of ash. For control purposes three of these mixed powders were again examined, the results proving them to be of the composition desired. They were then examined under similar conditions by the Röntgen rays, and the photographs obtained are now shown. The percentage of iron in the samples varied from 0·07 to 5·4, although, as stated above, the total ash contents were identical in each case. That sample which contained the least iron in the ash gave the clearest photograph, whilst that which contained most iron gave the worst, the other samples occupying intermediary positions in accordance with their varying iron contents. Hence it follows that the use of the Röntgen rays for fuel examinations, the author points out, is absolutely worthless, as it is the total ash contents which it is desired to determine by their aid.

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[*] *American Journal of Science*, vol. x. pp. 171–206.

[†] *Iron and Coal Trades Review*, vol. lxi. p. 673.

[‡] *Proceedings of the South Wales Institute of Engineers*, vol. xxi. pp. 483–526.

[§] *Stahl und Eisen*, vol. xx. pp. 392-393, with six illustrations.

[||] *Journal of the Iron and Steel Institute*, 1900, No. I. p. 442.

The Origin of Coal.—At the Bradford meeting of the British Association, the origin of coal and cognate matters were dealt with in several papers, including the following:—W. J. Sollas, on "A Concealed Coalfield beneath the London Basin;" W. Gibson, on "Rapid Changes in the Thickness and Character of the Coal Measures of North Staffordshire;" R. Kidson, on the "Flora of the Coal Measures;" A. Strahan, on the "Origin of Coal;" A. C. Seward, on "Botanical Evidence bearing on the Climatic and other Physical

Conditions under which Coal was Formed;" and J. E. Marr, on "The Origin of Coal."

A. Strahan refers to the unequal subsidence leading to the formation of coal-basins, parts of the margins of which are still recognisable. These were land surfaces in the coal measures, and it was generally accepted that the coal seams represented forests in the place of their growth. The existence of land surfaces was proved, but not that the coal-seams are forests. Rain-pittings, sun-cracks, and footprints occurred, not in the coals, but in the intervening strata. A large proportion of the erect tree trunks occurred in sandstones devoid of coal, a few only having been found to stand upon an underclay or to be associated with seams of coal. Vast areas of coal have been worked without any such trunks having been encountered. The land shells, insect, and reptilian remains were of rare occurrence. The underclays did not resemble soils, and were not always present beneath coal-seams, but often in or above them, and frequently had no coal associated with them. The persistence of the partings and characters of the coal over wide areas was in favour of their being subaqueous deposits, for on so large an expanse of land there must have been river systems and variations in the vegetation. Sub-aërial decomposition of part of a mass of vegetable matter would take place, whether it were floating or resting on dry land. Some coal-seams showed clear proof of a drifted origin, as those which were made up of a mass of small water-worn chips of wood or bark. The general sequence of events preceding the deposition of a normal coal-seam was, he thought, first, the outspreading of sand or gravel with drifted plant remains, followed by shale as the currents lost velocity. The water was shallow and sometimes retreated, leaving the surplus open to the air. The last sediments were very fine, homogeneous, and almost wholly siliceous, and in them a mass of presumably aquatic vegetation rooted itself and acted as an impediment to movement and further sediment. Then the material brought in consisted only of wind-borne vegetable dust or floating vegetable matter, with an occasional boulder. Lastly, the formation of the coal-seam was brought to a close by a sudden invasion of the area by moving water.

J. E. Marr argued that coal was a non-scientific term, introduced into scientific nomenclature for substances of divers characters, and therefore probably of different modes of origin. The Carboniferous period was one where the conditions suitable to the formation of coal were unusually widespread, for at that period there was a coincidence, such as never occurred either before or after that period, of dominant giant cryptogams, extensive plains of sedimentation, and advantageous climatic conditions. To advance our knowledge of the origin of coal several things were necessary, the chief being the importance of the study of the chemical composition of fireclays and other accompaniments of coal, in addition to coal itself; the continuation of Dr. Sorby's petrological work on the origin of grains of mechanically formed rocks, such as sandstones; the studies of fauna and flora throwing light on physical and climatic conditions; and efforts to discover over what periods coal formation occurred in exceptional amount.

A. C. Seward thinks that the alleged uniformity in the climate and vegetation during the coal period was exaggerated. It was important to bear in mind the progress of plant evolution as a factor. There was in coal-seams an abundance of spores with filamentous or hooked appendages, and their presence was probably due to floating or wind dispersal; and so also with detached stems and roots. Concerning the manner of formation of coal, A. C. Seward instanced the structure of calcareous nodules found in coal-seams, in which the preservation of delicate tissues, the occurrence of fungal hyphæ, and the petrification of stigmarion appendages was evidence in favour of the subaqueous accumulation of the plant *débris* found in the nodules. If ordinary coal were microscopically examined, it was found to contain spores—in abundance in cannel coal—fragments of tissues, bacteria, and the ground substance of coal. Boulders and coal-balls were also included in the seams. Hence he thought that the seams were not the result of growth in one place, nor of drifting, but of the accumulation of vegetable *débris*, derived chiefly from plants growing on the surface of large lakes and pools near to the borders, where they died and were carried out by gently flowing water and sank to the bottom over the whole water area.

Much discussion took place, and in the course of it P. F. Kendall combated A. Strahan's theory of sedimentation. There were wide extents of comparatively uniform thickness not only of the coal itself, but also of the over- and under-lying areas, such as the layer of black shale covered with marine organisms over an area of 700 square miles from Bradford to Nottingham. In respect of the purity of coal, the proportion of mineral ash was very small, and there was an absence of molluscs, fishes, or minute crustacea, and no trace of aquatic animals in the coal-beds, though they existed in the layers above. There was, again, no coal-bed without a seat-earth or under-clay penetrated by roots of trees; and there was an entire absence of alkalies, which was characteristic of an exhausted soil.

Composition of British Coals.—H. Louis[*] describes some investigations which had been made on behalf of the Swedish Board of Ironmasters[†] to determine the composition of samples of such British coals as were most largely used in Sweden. The samples were taken from coals ready for shipment. The results are summarised in a table giving the proximate and the ultimate analyses of about twenty-five different kinds of coal, together with their flaming and coking characters, and the nature of their ash. The process of analysis is also described.

Coal in Ireland.—A general review of the coalfields of Ireland has appeared, based on the reports of the various Commissions, and on the statements made by E. Hull. In conclusion it is held to be evident that there still remains a considerable quantity of undeveloped coal, both bituminous and anthracitic, as well as fireclays and iron ores of commercial utility. The past history of these coalfields is particularly unfortunate, and is not a true criterion of their value. The best seams of coal have been worked in an unscientific manner, and the state of the market has not been such as would cause capital to be attracted to this country for the purpose of pursuing a more intelligent system of working. On the other hand, it cannot be said that there is here an unlimited field for development. On the most sanguine estimate there is not much more coal in the whole country than would suffice to supply the present demand in the United Kingdom for even a single year; and a great deal of this is not of the best quality. The Irish coalfields, therefore, cannot be regarded as a reserve capable of prolonging to any appreciable extent the duration of the supply of British coal. But it is also certain that the present small output falls very far short of the capabilities of the country, and could be increased tenfold for the next two hundred years before the limit of exhaustion would be approached. This could scarcely be said of any of the existing coalfields of England or Scotland.[‡]

Brown Coal in Bohemia.—Owing to the scarcity of bituminous coal, brown coal is coming into increasing use on the Continent, and T. Kellen[§] gives a detailed description of the more important deposits. The best known varieties of brown coal are those from Brüx, which contains 52 per cent. of carbon, 3 per cent. of hydrogen, 16 per cent. of oxygen, and 4 per cent. of ash, and from Buschtiehrad, which contains 60 per cent. of carbon, 3 per cent. of hydrogen, 11 per cent. of oxygen, and 15 per cent. of ash.

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[*] *Transactions of the North of England Institute*, April 28, 1900.

[†] *Bihang till Jernkontorets Annaler*, 1900, pp. 1-37.

[‡] *Colliery Guardian*, vol. lxxix. pp. 1121, 1217.

[§] *Der Gnom*, May 10, 1900.

Coal in Bosnia.—The mining industry of Bosnia continues to make satisfactory progress. The interesting monograph written by Franz Poech on the occasion of the Mining Congress at the Paris Exhibition, which has been published in book form, clearly shows the importance of the mineral resources of the country, the chief mineral products being rock salt, iron ore, brown coal, manganese ore, copper ore, and iron pyrites. The administration of the mines is regulated by a law promulgated in 1881. Most of the mines and works belong to the Government. The reason of this is that after the occupation of the country few private capitalists came forward to establish industries, and the Government, full of good intentions to improve the economic conditions of the population, undertook to develop the mineral resources of the country. The results obtained have been satisfactory financially, and the Government has aimed at improving the methods of mining and the social condition of the population employed. Numerous houses have been built for the workpeople. For example, at the Kreka colliery there is a colony of sixty houses, each built for two families. These houses are one-storied, and each dwelling consists of a living room, a kitchen, a larder, and a stable, with a small garden in front and a kitchen-garden behind. For large families and for foremen one or two rooms are added. Married workmen pay for lodging 5 francs a month, bachelors 2 francs. Each mine is provided with an ambulance and co-operative stores, and sick clubs and insurance funds have been organised. At the end of last year there were 2090 members subscribing to the insurance fund.

In Bosnia and Herzegovina there are some extensive beds of brown coal, but no deposits of bituminous coal have yet been found. The coal-mining industry has grown in a remarkable manner since the first colliery was started at Zenica, as is shown by the fact that in 1880 the output was 500 tons, whilst in 1899 it was 303,425 tons. The coal is of Oligocene age. It is of a black colour, and yields on analysis :—

	Zenica.	Zgosca.
Moisture	11·80	6·55
Ash	6·55	12·32
Sulphur	2·48	2·01

Coal in France.—An exhaustive paper on the coalfield of the Gard has been published by M. Bertrand.* The monograph covers more than 100 pages, and is illustrated by numerous geological maps and sections. The results of the author's investigations are most encouraging from the point of view of the future resources of the region.

J. Gosselet † gives some notes on thirty-eight recent borings made in the North of France in search of the coal-basin. A map is appended.

F. Drobniak ‡ observes that the extensive Belgian coalfield, which is a continuation of the Ruhr, Inde, and Wurm coal-basins, passes into France in the neighbourhood of Condé, and then stretches for a distance of 68 miles in the Departments of the Nord and Pas-de-Calais, as far as Boulogne. The width of the field is but narrow, and the coal-seams are covered by tertiary deposits, frequently over 650 feet in thickness. Beds of quicksand are of frequent occurrence, especially in the Nord basin, and these greatly interfered with the progress of the coal industry in these fields. Thus, while in Belgium, in the neighbouring province of Hennegan, coal-mining commenced in the thirteenth century, and at the end of the seventeenth century there were some 120 shafts there with 5000 workpeople, the important coal deposits of France still lay quite untouched and unknown at the latter date. It was only in 1716 that a citizen of the town of Condé, thinking that the Belgian field must stretch into France, and investigating the question by operations in the vicinity of the village of Fresnes, proved the truth of his theory. His operations were very successful, and it is from these that the coal-mining industry of the North of France dates. Up to 1840 it was only in the Nord Department that coal was raised, and it was not until 1850 that coal-mining in the Pas-de-Calais became of any importance. The real progress of both Departments has been made since the year 1869.

The coal deposits are somewhat irregular in their occurrence, and occasionally the seams are greatly disturbed. The general strike of the beds is from east to west, passing subsequently in the Pas-de-Calais basin to south-east to north-west. The seams mined in the Nord basin vary in thickness, from 18 to 33 inches, with a local enrichment to 13 feet in the coal of the *grand veine* near Dutemple. In the Pas-de-Calais conditions are more favourable, the beds being far more regular and less disturbed, and the thickness of the seams reaching to over 8 feet. The author describes the systems of ventilation in use. Most of the collieries possess round walled ventilating shafts, which are also used for winding. In the colliery itself the ventilation doors are sometimes provided with explosion valves. The lamps are in the Nord basin all closed and of the Marsaut type. Open lights are occasionally used in the Pas-de-Calais. Transport in the colliery is usually done by ponies, only a few of the larger collieries having machine-driven plants for this purpose. The author describes generally the appliances and the systems of coal-getting adopted. Both long-wall and pillar-and-stall methods are in use, the latter far more frequently. The collieries usually have good repairing-shops, and are generally well provided with above-ground plant.

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* *Annales des Mines*, vol. xvii. pp. 505–618.

† *Transactions of the Institution of Mining Engineers*, vol. xviii. pp. 317–324.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. pp. 439–442, with sheet of illustrations.

An important memoir was read by Grand'Eury * before the Academy of Sciences, on the formation of coalfields, with special reference to the Loire.

J. Delas † has published an important paper on the lignite deposits of Sarladais, the output of which is 3882 tons annually. The author estimates that 14,000,000 tons of lignite are available.

Rock Temperature in the Ruhr Coalfield.—Kette ‡ publishes an exhaustive paper on the temperature of the strata in the Ruhr coalfield. The results of the observations recorded show that on an average the miners of the Ruhr coalfield have to reckon on an increase in rock temperature of 1° C. for every 92 feet, but that for those mines which are worked under very thick superincumbent strata a somewhat more rapid increase of temperature may be expected. This may, perhaps, amount to 1° C. for every 82 feet. Thermal gradients of 82 to 100 feet have hitherto been encountered only exceptionally, and are due to the action of hot springs and other special local conditions.

Quite a number of mineral springs have been met with in the Ruhr collieries as these have got deeper. It has now been ascertained that, at great depth, a bed of potassium salts underlies this field. The oldest and best known of such mineral springs is that of the Königsborn colliery, near Unna, which was known in the fourteenth century.§

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* *Revue Scientifique*, August 4, 1900.

† *Bulletin de la Société de l'Industrie Minérale*, vol. xiii. pp. 717–776.

‡ *Glückauf*, vol. xxxvi. pp. 733–740.

§ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. p. 533.

Brown Coal in the Cologne District.—Schott[*] has dealt with the brown coal industry of the Cologne district. The quantity of brown coal available is estimated at 3000 million tons. The bed is worked by quarrying, most of the product being moulded into briquettes, of which 930,000 tons were made last year.

An account has also been published[†] of the brown coal mining industry in the Rhineland. Information is given concerning the character of the deposits and methods of working.

Coal in Portugal.—Coal and iron ore exist in Portugal in abundance, and the deposits of ore are of such size, and these could be so easily mined, that the capability exists of an important iron industry. In addition, there is hard anthracite at San Pedro de Cova, where the deposit is known to cover more than 5000 acres, and a softer variety at San Pejao, where the quantity believed to exist is estimated at 11½ million tons. There are coal deposits at Cabo-Mondego, which are believed to be of great size, and which could readily yield 80,000 to 100,000 tons of coal a year, and valuable deposits of brown coal at Leiria. Limestone and manganese ore are also found. The transport facilities are, however, at present very inadequate.[‡]

Coal in Spain.—A detailed description has been published[§] of the coalfields of Puertollano and Utrillas, in Spain.

Coal in Nova Scotia.—F. H. Masou[‖] gives the results of a number of analyses of Nova Scotia coals, which have shown only feebly caking properties, and notes that these coals invariably show a considerably larger percentage of hygroscopic water than the caking varieties of the Nova Scotia coals. He finds that the British caking coals contain from 1·35 per cent. to 3·5 per cent. of water, while the British non-caking coals contain from 3·23 per cent. water to 11·29 per cent. water. Nova Scotia caking coals, however, contain as much as 3 per cent. of hygroscopic water, while the non-caking coals contain from 5 to 7·5 per cent. That the presence of water itself has nothing to do with the non-caking properties of the coal he has demonstrated by first carefully drying it at 100° C., and then attempting to cake it—without success; but it has occurred to him that the removal of the water, which is the first thing to come away on heating, leaves the coal in a porous state, and thus facilitates the rapid evolution of those hydrocarbons in a gaseous form which, if retarded, would liquefy, and thus form the cementing material of the coke. To test this theory, he tried heating some of the coal in Faraday tubes, where they were subjected to the pressure of the gases they evolved, and succeeded in getting a very fairly coherent coke.

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[*] Paper read before the *Verein Deutscher Ingenieure*, July 3, 1900.

[†] *Journal of the Society of Arts*, vol. xlviii. pp. 618–619.

[‡] *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. p. 225.

[§] *Revista Minera*, vol. li. pp. 282–283.

[‖] Paper read before the Mining Society of Nova Scotia.

Coal in Victoria.—J. Stirling has described the fossil flora of South Gippsland. The memoir has been published by the Department of Mines of Victoria as one of the special reports on the Victorian coalfields.

Coal in Natal.—W. T. Heslop * describes the coalfields of Natal, and gives the geological classification of the district. In the Cape Colony the coal measures are found overlying the Beaufort beds; at Vereeniging they lie directly on the Dwyka conglomerate; and in the Brakpan and parts of the Middelburg district they also overlie a conglomerate, which is probably of Dwyka age, although different in character from what is generally associated with the Dwyka conglomerate, the matrix being a coarse sandstone instead of a fine hard blue shale; but the enclosed pebbles and boulders are the same—*i.e.* quartz, quartzite, slate, and granite from the older formations. At Cypherfontein, to the south of Krugersdorp, the coal lies directly on the dolomite, and at Boksburg, on the Witwatersrand formation, the Main Reef series passes directly under the workings of the Wishaw Colliery. South African coal is generally considered to be a subaqueous and lacustrine deposit. Professor Green found in some of the Cape Colony coal, under microscopic examination, a distinct concretionary structure, and the writer has observed the same peculiarity in coal from the Brakpan district of the Transvaal, where, after weathering, the concretionary layers of carbonaceous matter readily peeled off. In the Natal coalfield the seams have been found at all depths up to 500 feet, but most of the existing mines are working at depths of less than 300 feet. The deepest shaft at present is that of the Durban Collieries Syndicate at Dannhauser, which is 500 feet deep. It is probable that workable coal may be found at a greater depth on the western portion of the coalfields, but up to the present it remains unproved. The occurrence of dolerite is extensive, and in certain large areas that have been examined by the writer, nearly three-fourths of the coal was found to be affected by igneous action. The annual output of coal in Natal during the last ten years has increased from 25,609 tons in 1889 to 387,811 tons in 1898. In last September, before the war broke out, 40,351 tons were produced from nine mines, 128 Europeans, 1678 natives, and 878 Indians being employed.

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* *Transactions of the Institution of Mining Engineers*, vol. xviii. pp. 410–430.

W. T. Heslop [*] also gives some notes on the value of Natal coal, referring to locomotive and other tests made with it, and giving comparisons with coals from other districts.

Coal in the Transvaal.—Detailed descriptions have been published of the Middelburg coalfield [†] and of the East Rand coal district.[‡]

Coal in Alabama.—The Geological Survey of Alabama has published a report on the Warrior coal basin from the pen of H. M'Calley. The map accompanying the report shows the outcrop of all the principal seams and the position of the collieries.

A description has been published of the Alabama coalfield.[§] The importance of this field, and the effect it is destined to have upon the foreign as well as the home supply, are discussed.

C. Catlett [‖] presents a study of typical sections of coal outcrops from a wide territory, covering Virginia, West Virginia, Kentucky, and Alabama, of which six sections out of thirteen show an increase in coal thickness of 6·45 per cent. on being driven under cover; seven sections out of thirteen show a decrease of 4·75 per cent. in the coal thickness on being driven under cover; six sections out of eleven show a decrease of partings, on being driven under cover, of 30·24 per cent.; five sections out of eleven show an increase in partings, on being driven under cover, of 27·46 per cent.

The views expressed tend to show that it is better to prospect a coal property by making a number of openings along the outcrop than by drifting under cover.

Coal in Indian Territory.—The United States Geological Survey has published a memoir by J. A. Taff [¶] on the geology of the

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[*] *Colliery Guardian*, vol. lxxx. p. 168.

[†] *Mining Journal*, vol. lxx. pp. 1003–1050.

[‡] *Ibid.*, p. 1061.

[§] *Engineering*, vol. lxix. pp. 737–739.

[‖] *Transactions of the American Institute of Mining Engineers*, Canadian meeting.

[¶] *Nineteenth Annual Report*, Part III. pp. 423–600.

M'Alester-Lehigh coalfield, Indian Territory. The coals are all highly bituminous. The volatile matter in no instance is less than 37 per cent., and the fixed carbon averages 52 per cent. There are 58 square miles of workable coal in the Hartshorne bed, 60 square miles in the M'Alester bed, and 25 square miles in the Lehigh district.

Coal in Kansas.—Charles R. Keyes* discusses the correlative relations of certain subdivisions of the coal measures of Kansas, and calls attention to similarity of results obtained forty years ago, and conclusions arrived at by recent workers.

The Trans-Mississippian Coal.—C. R. Keyes† sketches the geological position of the coal-bearing rocks in the great western interior coal basin on the west of the Mississippi. The Carboniferous system is now divided into the Upper or Missourian series and the Lower or Des Moines series, and these are again further subdivided. Over 90 per cent. of the total coal production comes from the Cherokee shales at the base of the Des Moines series, taking the average of Iowa, Kansas, Missouri, Arkansas, and Indian Territory, and the value of this horizon is almost sure to increase.

Coal in Michigan.—A. C. Lane‡ gives a sketch map of the coal basin of Michigan, where the output for 1899 was over half a million tons. The increase in the production has been rapid within the last few years, but the extensive forests and other matters have delayed the development. The usual thickness of the seams worked is 2½ to 4 feet, at a depth from 100 to 300 feet. Many of the coals contain much sulphur. The various mines are shortly described.

Coal in Missouri.—David White§ has prepared a monograph of the fossil flora of the lower coal measures of Missouri. As the first comprehensive presentation of the flora of any zone of the coal measures in the trans-Mississippi region it furnishes valuable material for comparison and correlation of these beds with the eastern coalfields.

Coal in New Mexico.—C. L. Herrick‖ and T. A. Bendrat, in a paper on the identification of an Ohio coal measures horizon in New

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* *American Geologist*, June 1900.

† *Engineering and Mining Journal*, vol. lxix. pp. 528–529.

‡ *Ibid.*, vol. lxix. p. 767, vol. lxx. p. 12.

§ *United States Geological Survey Monographs*, vol. xxxvii.

‖ *American Geologist*, April 1900.

Mexico, direct attention to the remarkable similarity of forms in the measures near Newark, Ohio, and Albuquerque, New Mexico.

Coal in Pennsylvania.—G. M. Williams,* discussing dangerous outcrops under quicksand deposits, illustrates and describes deposits in the Wyoming basin in Pennsylvania, and states the reasons why their working is an exceedingly dangerous operation.

The Coos Bay Coalfield, Oregon.—In an exhaustive paper, illustrated by thirteen plates and sixty figures in the text, J. S. Diller † accumulates evidence to show conclusively that the pitch-coal of the Coos Bay coalfield is an asphalt showing none of the characteristics of coal, the chief points being fusibility, manner of burning, action of solvents, peculiarities on distillation, similarity of distillate to the distillates of bodies unquestionably classified as asphalts, and the separation of pyridine and quinoline bases, which seem to be rather characteristic of California and other Western bitumens. The properties of the coal, on the other hand, are those of true coal, and the difference between the ashes of the two are such as to furnish strong argument against common origin.

Coal in India.—G. F. Reader ‡ gives a preliminary report on the part of the Rampur coalfield, lying between parallels 21° 45′ and 21° 51′, and meridians 83° 50′ and 84° 1′. A number of bore-holes have been sunk and some more or less indifferent seams found. Some notes are also given on the Sohagpur coalfield, where several seams of coal, ranging from 15 per cent. of ash and upwards, are found. Two seams are of workable thickness and fine quality.

Coal in Central Asia.—Some account is given § of important coal discoveries which are stated to have been made in the Margellan district of Central Asia. The most important deposit appears to be that of Ütschkurgan, 20 miles from the new Margellan railway station. It has an area of 16 square miles. The coal is stated to be quite free from sulphur, to contain very little ash, and to be better than that of the Donetz basin.

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* *Iron and Coal Trades Review*, vol. lxi. p. 67.

† *United States Geological Survey, Nineteenth Annual Report*, Part III. pp. 309-376.

‡ *General Report of the Geological Survey of India*, 1899-1900, pp. 63-73, with map.

§ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. p. 559.

Coal in China.—A recent consular report by Carles of Tientsin gives a number of particulars relating to coal and coal-mining in China, and deals more especially with the question of transport.

P. Fouletier * describes the Kebao collieries, Tonkin.

T. Webster † describes the Tong colliery, Kaiping, North China. There are thirteen seams, dipping from 45° to 90°, and nine are workable. The pillar-and-stall system is employed. The winding, pumping, and other plant is shortly described.

Coal in Chili.—Some interesting details of coal in Chili have been published.‡ The calorific powers of some of the principal coals are as follows:—

	Calories.
Talcahuano:—	
Talcahuano	5468
Penco	5764
Santa Ana	5559
Dichato	4913
Lautaro:—	
Coronel	5630
Lota	6472
Arauco:—	
Colico	5950
Curanilahue	6182
Lebu	6472
Nielol (lignite)	5123
Merced (lignite)	2563
Quilacoya (anthracite)	7320

Analyses of lignite from various localities gave the following results:—

	I.	II.	III.	IV.
Water	18·4	17·6	18·80	25·5
Gas	31·6	38·8	28·85	18·0
Coke	36·5	40·2	50·20	22·0
Ash	13·5	3·4	2·15	34·5

I. Chumai outcrop; II. Malalhue; III. Nielol; IV. Los Corrales. Last year the imports of coal into Chili amounted to 661,669 tons.

Coal in New Caledonia.—Coal is known to exist in abundance in the French colony of New Caledonia,§ and is stated to be of fairly good quality, suitable for steaming purposes. At no time, however, do the deposits appear to have been extensively worked, and at the present time no coal is being mined, all supplies being imported from Australia. The old workings, which appear to have been very limited, have either fallen in or become drowned out, and only highly inclined outcrops of impure coal are visible. All the coalfields of the colony are on the western side of the island, and may be divided into—(1) Basin of Noumea, including Mont d'Or, Dumbea, and Païta; (2) basin of Moindou; (3) basin of Poya; (4) basin of Voh. A number of assays show 72 to 86·5 per cent. of fixed carbon and 1·7 to 21·5 per cent. of ash. At Magenta, near Noumea, the coal is said to be much broken up, but in other basins there are unfaulted seams up to 6 feet thick. The limited consumption and the lack of means of transport account for the want of enterprise in opening up these mines, but if the railway from Noumea to Bourail, a distance of 125 miles, is made, it will go far towards overcoming these difficulties.

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* *Comptes Rendus de la Société de l'Industrie Minérale*, 1900, pp. 45–61.

† *Proceedings of the South Wales Institute of Engineers*, vol. xxii. pp. 24–36.

‡ *Revista Comercial e Industrial de Minas*, vol. i. No. I. (February).

§ *Colliery Guardian*, vol. lxxx. p. 386.

Coal in Spitzbergen.—As a result of the examination by German explorers of the rich coal-mines in the Arctic Islands, several companies have been formed in Norway, and expeditions have been sent to the island of Spitzbergen. One expedition, led by the engineer Nilson, was very successful, and has opened some mines on the Ice Fiord, which are to be worked next year. They brought back about 1000 hectolitres of what is said to be excellent coal. The coal seams are above the sea-level, and three of them are from 6 to 9 feet thick. Furnace coal, it is said, is found in Green Harbour, at the end of the Ice Fiord. The strata are described as so rich that they can supply the whole demand of Northern Norway for an unlimited period. The facilities for export are, on the whole, very good; but, according to the *Vossische Zeitung*, the coal must be transported by lighters on board the ships, and the piers must be removed every winter to prevent their destruction by the ice.

According to F. Mewius,* coal seams occur both in Spitzbergen and in Bear Island. The coal-bearing strata consist of sandstone, shale, and limestone. In Spitzbergen the seams are insignificant, but in Bear Island there are three of workable thickness.

Peat.—C. Baskerville † has found titanium, chromium, and vanadium in the ash of samples of peat from North Carolina.

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* *Berg- und Hüttenmännische Zeitung*, vol. lix. pp. 499–501.

† *Journal of the American Chemical Society*, vol. xxi. pp. 706–707.

III.—*CHARCOAL.*

The Manufacture of Gas from Charcoal.—J. M. Neil [*] describes the Riché continuous retort for the manufacture of charcoal and gas. The retorts are vertical and are heated externally. Charcoal is withdrawn at the bottom, which has an L-shaped extension, and wood is charged at the top. The gas is also drawn off below. A ton of wood is stated to produce 400 lbs. of charcoal and 25,000 cubic feet of gas, containing 44·2 per cent. of hydrogen, 22·0 of carbon monoxide, and 21·3 of carbonic anhydride.

Dry Distillation of Fir Wood.—Irminger [†] describes some tests of the dry distillation of fir. The total weight of the products of distillation—gas, pyroligneous acid, tar, and charcoal—was within 4 per cent. of the weight of the wood charged into the retorts.

IV.—*COKE.*

Beehive Ovens.—A description is given [‡] of the beehive coke-oven plant at Chickamauga, in Georgia, with dimensions of the ovens, and an illustration of the inclined track and hauling plant for running the loaded trucks over the ovens.

F. C. Keighley [§] gives an illustrated description of the Connellsville coke district, with especial reference to the mining of the coal.

A. W. Evans [||] describes the coking plant of the Durham Coal and Coke Company. An illustrated description of a plant on Lookout Mountain, Georgia, is given.

A brief description has been published [¶] of the Welsh coke-ovens used in West Virginia in place of beehive ovens.

Coke-Oven Plant of the Concordia Colliery.—The coke-oven plant of the Concordia colliery, Moravian-Ostrau, is stated by W.

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[*] *Engineering and Mining Journal*, vol. lxx. pp. 281–282.

[†] *Ingeniören*, Copenhagen, 1899, pp. 311–317; *Minutes of Proceedings of the Institution of Civil Engineers*, vol. cxlii. p. 439.

[‡] *Colliery Guardian*, vol. lxxx. p. 610.

[§] *Engineering Magazine*, vol. xx. pp. 17–40.

[||] *Mines and Minerals*, vol. xxi. pp. 49–51.

[¶] *Ibid.*, p. 11.

Jicinský* to have been originally laid down in 1862, when beehive ovens were erected. Some years later these were replaced by Appolt ovens, and of ovens of this type eight are still in use, but will cease to be employed within the next two years. Of horizontal coke-ovens there are now 85 in use, but an additional 100 are being erected. The coal is brought to a fine state of division by a special plant, and is then stored in a coal "tower," which will hold 2000 tons. From this it is taken by a wire ropeway to the coke-oven. The finished coke is similarly conveyed by a wire ropeway to the blast-furnaces. Electrically-driven rams are being employed with the new coke-ovens. The coal is first compressed before being charged into the oven. The waste heat from the coke-ovens is used for steam-raising purposes. At present 500 tons of coal are coked daily, but when the whole plant has been erected over 700 tons will be the daily quantity. The coke-ovens are arranged for the collection of the by-products, there being two condensing plants in use. The ammonia water collected is converted into ammonium sulphate, and benzol is also to be collected. The coke made is passed through trommels and sized. In 1888 85,000 tons of coke were made, but now the annual out-turn is 130,000 tons, and will be some 180,000 tons when the plant is complete. In addition to the coke there is now produced about 2000 tons of ammonium sulphate and 6500 tons of tar.

By-Product Coke-Ovens.—In a recently published pamphlet † reference is made to the fact, previously pointed out in these abstracts, that, in addition to many other types of less importance, there are two new systems of coke-ovens in general use—the Semet-Solvay and the Otto. The first six experimental ovens on the Semet-Solvay system were erected in 1882 at the Bellevue Colliery, belonging to the Société des Charbonnages de l'Ouest de Mons. About a year later twenty-five more such ovens were erected in the vicinity of the Havré Colliery, and from that time on the use of these ovens spread with considerable rapidity. The ovens themselves have not undergone any great structural changes with the passage of time. Some of the ovens at the Havré works have been in use for over ten years without the slightest repair having been necessary. This is a point which has been somewhat questioned.

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* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen; Beilage*, vol. xlviii. pp. 80–81.

† *Fours à Coke*, Brussels, 1900. A copy is in the Institute Library.

The ordinary dimensions of an oven are as follows :—Total length, 29 feet 6 inches; height, 5 feet 7 inches; breadth, from 14·1 inches for a coal with but little volatile matter, to 19·7 inches for a coal containing a higher percentage of volatile constituents. Of late some ovens of larger dimensions have been erected, with a result that the cubic contents of the oven have been raised in these cases from the average of 238 cubic feet to 353 cubic feet. An oven of the larger size yields annually about 1800 tons of coke. The finished coke is pressed out in a thin layer, and the quenching is stated to be consequently rapidly effected, and only a relatively small quantity of moisture to be retained. It is preferred to cool the gas at once after it escapes from the ovens, with a view to avoid tar settling in improper places in the subsequent passage of the gases through the condensing plant, and so causing inconvenience. The charge of an oven is about four to five tons, and the time required for coking is less than twenty-four hours. The wages paid are not higher than in ovens of the ordinary kind. To these, however, must be added the wages connected with the cooling and washing plants.

There is no special arrangement for the pre-heating of the blast other than in the utilisation of channels beneath the oven bed. In these the temperature of the air is raised to 200° or 300° C. Special attention is paid to a careful regulation of the gas supply to each oven, the gas openings leading from the ovens to the main gas channel being of such a size as to cause the draught to be of equal strength for each oven. Boilers are placed between the oven and the stack. According to the kind of coal being coked, the heating surface of each oven varies from 64·6 to 134·5 square feet. The temperature of the gases, as these escape into the stack, is stated not to exceed 200° C., even when the furnace is working hot. The steam raised in the boilers by the waste heat usually suffices for the coke-oven plant, and also the ammonium sulphate plant. Only a portion of the gas produced is used for heating purposes. The quantity of gas that remains in excess varies greatly, and is dependent on the character of the coal. It is stated, however, to be at least one-fourth of the total quantity produced, even when a coal is being coked that is low in volatile constituents. The larger the quantity of these, the greater is the available excess of gas. When coal low in volatile constituents is being coked, the quantity of water converted into steam by the direct use of the waste heat of the oven is stated to amount to 0·6 lb. for each pound of coal charged. If the excess of gas is also used for steam-raising purposes, then this quantity becomes 0·9 lb., or even 1·25 lb. in the case of coal high in volatile constituents. It is pointed out that a large saving is in this way effected as regards the coal that would otherwise have to be used for raising steam. The use of the excess of gas for power production has existed for some time at the Cockerill Works, where an 8 h.p. motor gas-engine has been worked by such gas, and utilised for electric lighting purposes. No practical difficulties have been experienced, and it has been decided to erect two new 20 h.p. gas-engines, which will also be served by the waste furnace gas. The calorific power of the gas from the Semet-Solvay ovens at Seraing has been found by the calorimetric bomb to amount to 4500 calories. The gas consumption per hour h.p. is about 28·25 cubic feet. The advantage of the use of the gas direct for power-raising purposes, or indirectly by use for raising steam, is shown by the author to be very great. The waste gas can, too, be used for illumination. It is of 16 to 20 candle power in the case of a coal specially suited to yield gas of this kind. With regard to the cost of construction of the Semet-Solvay oven details are given. The total cost of an oven was in Belgium about £240, but this does not include the cost of the condensing plant. This is considerable, amounting to an additional sum of about £160, thus making the total cost per oven about £400. At present, it is pointed out, the prices of materials are so high that the above figures are not to be taken as accurate. It is claimed for the Semet-Solvay ovens that these have a high annual out-turn; that they can make excellent coke out of even poorly caking coals which are difficult to deal with in ovens of other types; that a high yield of coke results; that repairs to the ovens are very readily effected; that long campaigns are possible; and that the flues can be readily inspected.

Details are given as to the Semet-Solvay plants that have been erected or are in course of erection. The former number thirty-two with 1451 ovens, and the latter seven with 357 ovens.

In a paper read on February 21, 1900, before the *Verein deutscher Fabriken feuerfester Producte*, E. F. Dürre describes the Otto and Bauer coke-ovens. In the Bauer system each oven in a battery is dealt with as an individual, and not merely as part of a series of ovens. Through the whole battery run channels into which the various ovens open. These ovens have, so far, given good results. In the Otto system described by the author, the gas channels are at the top and not at the bottom. The author refers to the possible use of waste blast-furnace gas in coke-oven practice, and points out that blast-furnace gas possesses the great disadvantage that it carries with it so much metallic dust that it may be unserviceable.

A plan has appeared * of the new coke-oven plant in the course of erection at Sidney, Cape Breton. It will contain eight batteries, each of fifty Otto-Hoffman ovens, to produce 1600 tons of coke daily. The gas will be used for lighting purposes, as with the Everett plant, near Boston, to which this is similar, and the coke will be used for the Dominion Iron and Steel Works.

R. Brunck † observes that a number of batteries of coke-ovens of the Brunck type have been erected in the Rhenish-Westphalian district. Improvements which were introduced as the result of practical experience are referred to by the author. These result in the two sides of the furnace being separately heated, the waste gases being withdrawn by separate flues from each side. A very considerable preheating of the air for the combustion is attained, this passing up through a kind of firebrick stove between the two channels through which the gases pass to the stack. In this way overheating of the brickwork is prevented, and a considerable portion of the heat saved which would otherwise have escaped with the waste gases. Details are given of the oven construction; and it is pointed out that the gases from the coal are exposed for a shorter time to the danger of combustion and the heat of the oven than in other systems, with the result that a higher percentage of by-product is attainable.

Illustrations are given of the coke-oven plant on this system at the Jules Chagot Works at Montceau-les-Mines, and at the Minister Stein Colliery of the Gelsenkirchen Company. At this latter place there are 120 ovens, which coke in the course of a year from 250,000 to 260,000 tons of coal, containing 10 to 12 per cent. of moisture; this yields from 2800 to 2900 tons of ammonium sulphate and some 7500 to 7800 tons of tar. Other plants illustrated include one of sixty ovens at the Alma colliery of the Gelsenkirchen Company, and one of thirty ovens at the Hoesch Steelworks near Dortmund.

W. G. Irwin ‡ discusses the general aspect of by-product coking in Western Pennsylvania, and briefly reviews its present condition and the advances recently made. The transfer of the ovens to the works is held to have many advantages, as, though the cost of transport of raw coal is greater, yet the excess gas may be used where it is wanted.

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* *Colliery Guardian*, vol. lxxx. p. 801.

† *Stahl und Eisen*, vol. xx. pp. 685–690, with five illustrations and one plate.

‡ *Engineering and Mining Journal*, vol. lxix. pp. 711–712.

Desulphurisation of Coke.—The various methods of desulphurising coke are reviewed,* and it is pointed out that the only methods, out of all those that have been proposed, that are in any way successful, consist in washing the coal and in adding lime.

V.—*LIQUID FUEL.*

The Use of Liquid Fuel.—J. Preiner,† discussing the use of liquid fuel in metallurgical processes, observes that it has long been so employed for steam-raising purposes in boilers. For years past all the steamers on the Caspian Sea and the Volga have used petroleum as fuel, and so too have many railway engines, as well as the petroleum distilleries at Baku. In recent years it has been used for smelting purposes, and has now attained considerable importance for this purpose, especially in Russia. There are in that country metallurgical works in which no solid fuel is employed at all, only petroleum being used. Petroleum-firing is especially employed for open hearths and crucible steel furnaces, as well as for puddling, heating, drying, and other furnaces. Indeed, petroleum has been found a satisfactory fuel for almost all metallurgical processes. It is only in the case of shaft-furnaces that petroleum firing cannot be employed, the use of solid fuel being necessary in these to keep the charge porous.

Russian petroleum is a thin fluid, very dark brown in colour, and has a specific gravity of from 0·85 to 8·97. Like all petroleum, it consists of various hydrocarbons, and contains :—

Carbon.	Hydrogen.	Oxygen.
85·3 to 86·0	16·6 to 13·0	3·1 to 1·0

The chief deposits of petroleum in Russia lie to the west of the Caspian Sea, in the neighbourhood of Baku. Quite recently, the steppes to the north and north-east of the Caspian have been searched for oil, and paying results are expected. The right to raise petroleum formerly belonged exclusively to the Russian crown, and it was not until 1872 that permission was given to others to raise oil. The raw petroleum is mostly distilled at the spot where it is won, only about a tenth part being sold in the raw state. Of the raw oil raised at Baku about a half consists of these "petroleum residues," termed in Russia "Astatki" or "Masut." Their specific gravity is about 0·95, the calorific power being about 11,000. Theoretically they are capable of replacing about twice their weight of good brown coal, and do so in practice. At Baku, in 1898, these residues cost about 10s. the ton, but transport charges bring the price up to about 35s. the ton at Moscow, or half that at Saratov, a town on the Volga. Notwithstanding this, these residues are used with commercial advantage in open hearths and heating furnaces at Moscow. Works using petroleum as fuel make neither smoke nor clinker. No fire-bars are required, and no gas producers. There is no loss of fuel either, as the petroleum is brought to the furnaces in closed vessels, and then burns with an almost theoretical degree of perfection. One great advantage of the use of petroleum is that the labour costs for firing are reduced to a minimum. There are three main types of firing methods with petroleum—(1) the pan method, (2) the drop method, and (3) the spraying method, in which the oil is, as it were, pulverised before use. Each of these is illustrated. In the first method a series of rectangular cast iron pans, from three to five in number, are placed one above the other, fitting closely to the walling at the sides. Between each two pans a slit is left of an area that has been carefully calculated, and through which the air streams that is to serve for the combustion. The naphtha residues flow into the upper pan through pipes from a large wrought iron tank which is placed at a higher level. By regulating the flow of oil, the whole of the pans may be kept full without overflowing. This pan system of firing possesses a certain analogy with the step grate. It is the oldest and simplest, but least economical, of the various methods. It is frequently employed, and is, indeed, not replaceable by other methods when it is a question of producing a temperature that is to be increased slowly. Very high temperatures can be attained by this method, especially if the air for the combustion is pre-heated. Crucible steel can, indeed, be made with this system of firing in the so-called Nobel furnace. It is, however, most applicable when it is not a question of producing a very high temperature. The second method is considerably better than the one just described, and is more frequently employed. In this method the oil flows out in drops or in thin streams from a number of small tubes placed side by side, or from a launder provided with a number of slits. In falling, it gets intimately mixed with air, and burns more readily and more completely than does the oil in the pan method. A higher temperature can, too, be more rapidly attained, and there is less chance of loss of oil. The drop method from a pipe apparatus is better than that in which a launder with slits is employed, as the former is much more under control. This drop method is very useful for heating furnaces. The height of fall of the petroleum regulates the temperature that results. For small firings it is about 39 inches, and rises to double that in larger ones. The air for the combustion either takes the same course as the falling oil, or else passes upwards in the opposite direction. This system of firing has this one advantage over all others, that once started it involves no labour charges whatever in the case of furnaces that are constantly in use. The first and second methods differ from the third in that the oil falls or flows from a higher level, and still more distinctly in that the oil is not charged as such direct into the furnace, but is first gasified in a more or less small gasifying chamber, this space resembling the grate in the case of a furnace using solid fuel. In the third or spraying system a blow-pipe jet is used. The oil flows into the inner tube of a blow-pipe, compressed air or steam being forced through an outer tube surrounding the other. This air or steam meeting the oil as it flows out completely disseminates it, and producing an intimate admixture of air and steam, enables the most rapid degree of combustion to be attained. The gasification stage is avoided, and the combustion chamber is the furnace itself. This spraying method, in addition to an ideal degree of simplicity, has the further advantage that the flame may be given any desired length or direction, while the quantity of fuel can be regulated with the greatest precision, and any desired temperature can be attained. There is still another advantage, in that by varying the construction of the spraying appliance the flame may have any shape given to it that is wished for. For instance, in boiler-firing a long broad flame is desirable, the flame lapping the sides of the boiler-tube, and the author illustrates a modified form of burner which gives a flame of this shape. Other types are also shown. Thus, if a large space has to be equably heated, a pipe form is employed with a spiral-shaped opening, which results in the steam or compressed air attaining a rotary movement, and so giving a flame of conical form. Pipe forms are used in all kinds of fusion furnaces for the production of weld and ingot iron. Not only have open hearths and puddling furnaces been provided with such appliances, but two years ago a crucible steel furnace heated in this manner was erected. The fusion furnaces, with petroleum firing, are built on the regenerative system, in exactly the same form as for gas firing. Four 15-ton open hearths of simple form at Moscow are described. These have petroleum firing on the spraying system. The river Volga, which offers the best transport line from the petroleum districts to the works, is thickly frozen over in winter, and this necessitates the works providing themselves with large storage reservoirs for the oil. These are of iron, and are cylindrical in form. Large stores of oil mean, of course, great danger from fire, and the works consequently only purchase residues whose flaming point is as high as possible above 120° C. It is not an uncommon thing to find, however, that ordinary raw oil is mixed in with the residues as an adulteration, and, indeed, to such an extent that the temperature at which the oil will fire may be reduced to as low as 80° C. The first cost of a naphtha plant for a works with two open hearths, one crucible steel furnace, six other furnaces, and some smiths' fires, &c., together with a boiler-house containing 11 boilers, amounted to 27,000 roubles, 15,000 of which was the cost of the storage vessel, the remainder being expended for two pumps, pipe lines, &c. The author, in conclusion, draws attention to the rapid rate of progress of the Russian iron industry.

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* *Engineer*, vol. xc. pp. 229–230.

† *Stahl und Eisen*, vol. xx. pp. 424–429, with eight illustrations.

C. M. Rolker * describes the Elmore ore concentration process as used at Glasdir, in Wales, for concentrating copper ore. The ore is mixed with oil and then thrown into water. The gangue sinks, but the sulphides remain floating with the oil, if the correct proportions are used.

Roux † gives some notes on the use of petroleum in the manufacture of coal briquettes.

C. F. Z. Caracristi ‡ gives statistics for the world's production of oil, and briefly describes the leading oil districts.

H. Guérin § summarises recent articles describing the best methods of using liquid fuel.

Chemistry of Petroleum.—A. A. Shukoff || and N. S. Pantjucoff describe their investigations on the existence of paraffin in Russian oils, and show that it may be extracted.

D. T. Day ¶ gives some notes on the variation of the crude oils from

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* Paper read before the Institution of Mining and Metallurgy.

† Paper read before the Paris Petroleum Congress; *Petroleum Review*, vol. iii., Supplement, p. 80.

‡ *The Mining Industry*, vol. viii. pp. 454–466.

§ *Génie Civil*, vol. xxxvii. pp. 22–25, 36–39.

|| *Petroleum Review*, vol. iii. p. 153.

¶ Paper read before the Paris Petroleum Congress; *Petroleum Review*, vol. iii., Supplement, p. 9–10.

Pennsylvania and Ohio, and shows how filtration through fuller's earth and other materials alters their characteristics.

C. Engler* again describes and discusses at some length the various theories for the origin of petroleum.

C. F. Mabery † discusses the composition of American petroleums, especially those of Ohio, California, and Canada, dealing with the sulphur and nitrogen compounds and with the solid hydrocarbons.

B. Redwood ‡ discusses the desirability of uniformity in methods of testing petroleum and its products, and shows how results vary unless the conditions are carefully prescribed and adhered to.

S. F. Peckham § discusses the classification of crude petroleums. At present four or more commercial types are recognised, viz., paraffin, Russian, sulphur, and nitrogen petroleums. The classification should be founded on a chemical basis.

V. Markovinikoff‖ describes the chemistry of the Russian petroleums.

K. W. Charitskoff ¶ also deals with uniform methods of investigation for petroleum products.

R. Zaloziecki ** describes some solid hydrocarbons of high melting-point from the final distillation products of petroleum.

Geology of Petroleum.—At the Paris Congress on petroleum some discussion arose on the desirability of recording the depths of wells in relation to the sea-level, or to some other fixed datum line for the district.

H. Höfer followed with a discussion of the anticlinal theory, and other theories dealing with the distribution and origin of oil.

H. Höfer †† deals elsewhere with the various theories relating to the origin of petroleum, and also with the geology of the subject.

Petroleum in Roumania.—J. Tănăsescu ‡‡ gives the results of an official investigation into the constitution and properties of the Roumanian petroleum, made in connection with the exhibit of this oil at the Paris Exhibition.

This petroleum contains only traces of oxygen. Hell and Medinger have shown the presence in a Roumanian petroleum of a substance of the composition $C_{11}H_{20}O_2$, and, further, that nearly all petroleums contain oxidised compounds which are soluble in alkalies, more being present in the heavier than in the lighter oils. Sulphur and nitrogen are also found in some petroleums, but in small quantities only, and it is not yet definitely known in what form. The Berca oil was especially selected for examination in this investigation of Roumanian oils. It has a specific gravity of 0·8240 at 15° C. When distilled in an Engler apparatus it yielded :—

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* Paper read before the Paris Petroleum Congress; *Petroleum Review*, vol. iii., Supplement, pp. 17–21.

† *Ibid.*, pp. 26–30. ‡ *Ibid.*, pp. 31–33. § *Ibid.*, pp. 39–41.

‖ *Ibid.*, pp. 42–44. ¶ *Ibid.*, p. 76. ** *Ibid.*, p. 77.

†† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. pp. 525–527; Paper read before the Paris Petroleum Congress.

‡‡ *Ibid.*, vol. xlviii. pp. 427–430.

Temperature.	Per Cent.
Up to 150° C.	23·19
150 to 300° C.	46·30
Residue	30·20

This residue was rich in paraffin. Analysis showed the composition to be—

Carbon.	Hydrogen.	Sulphur.
85·08	13·71	0·20

The results of a very complete fractional distillation are given, as also are those of subsequent examinations of these distillates. The results showed that the oil contained large quantities of hydrocarbons of the benzene series. Other Roumanian petroleums contain these hydrocarbons, those of Casin and Resca only containing small quantities, while others contain more, such as those of Colibasi and Cămpeni. Roumanian petroleums vary very greatly in colour. That of Cămpeni-Părjol is transparent and of a light yellow colour, while that of Predeal possesses a light reddish colour. All the other Roumanian petroleums are opaque and show every variation of the darker colour between brown and black. A more or less green fluorescence is characteristic of them all. With regard to their density, the lightest oil, 0·7838 at 15° C., is that of Cămpeni-Părjol. The oil with the highest density, 0·9050, is that of Sărata-Tohani. Saligny states that the petroleum of Ocnita has the density 0·9443. As a rule the density varies from 0·79 to 0·87. Some of the oils have a pleasant, and others an unpleasant, smell. Almost all the Roumanian petroleums contain highly volatile constituents, and even gases. The degree of viscosity was tested by means of the Engler viscosimeter, and found to vary from 1·04 for the Cămpeni oil to 4·88 in the case of that from Sărata-Tohani. This latter oil contains somewhat large quantities of oxidation products, which are soluble in alkalies. The physical properties of the various commercial products that are obtained from the unrefined Roumanian oils are then described, and it is shown that many of them are well suited for the manufacture of illuminating oil, the lighter "essences," and paraffin, while others are well suited for the manufacture of lubricating oils.

A recently published work by L. Edeleanu and G. A. Filiti * deals with the composition of petroleum, especially of that of Roumanian origin. Some twenty-six samples from various districts are examined both chemically and physically, and the results are given in detail.

C. Alimanestiano † and L. Edeleanu, at the Petroleum Congress at Paris, gave a full account of the Roumanian oil industry, and dealt with the history, geology, composition, and characteristics.

N. Coucou ‡ also gives many particulars of this oil-producing country.

Petroleum in Russia.—A committee has been formed under the presidency of Devi, member of the Russian Mining Department, to decide the question of the exploration of petroleum under the sea near Baku. The points to be decided are: (1) The suggestion of the Technical Committee for the preservation of the Baku oil-fields, to reclaim that part of the sea by filling it in, so that the new petroleum plots may be joined to the old plots, and so form one field, or to reclaim by some special means single spots forming islets not connected with the mainland. To ascertain the depth of the sea over the submarine petroleum deposits, and the extent of that zone. (2) What measures should be taken to prevent accidents to workmen by fire, and also for securing the works on the submarine oil plots from destruction, and from the access of the sea-water into the tubes of the wells, and the wasting of the oil from the fountains. (3) What measures should be adopted to prevent the new works on the sea from interfering with the shipping entering or leaving the port of Baku. (4) What should be the size of the new plots, taking into consideration the cost of creating the same. (5) Whether the plots shall be leased out by auction or the leases be granted to persons selected by the Ministers of Agriculture and State Domains.§

V. Latkin || discusses the position of the export of oil from Baku after the opening of the pipe line from Michaelova to Batoum. Its length is about 147 miles, and it will be capable of carrying 60,000,000

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* *Contributie la Studiul Petrolentin din tara*, Bucuresci, 1900; *Bulletin de la Société Chimique*, vol. xxiii. pp. 382–403; *Petroleum Review*, vol. ii. p. 386.

† *Petroleum Review*, vol. iii., Supplement, pp. 5–9.

‡ *Ibid.*, pp. 22–26.

§ *Engineering and Mining Journal*, vol. lxx. p. 313.

|| *Petroleum Review*, vol. ii. pp. 253, 290.

poods of refined oil, so that the present railway capacity will be increased. Siding accommodation is, however, very scanty, and the pipes and pumps used for filling the tank-waggons are inadequate, so that much time is lost. There are three pumping stations on the line, with Worthington pumps.

A. A. Shukoff and N. S. Pantjucoff * show that paraffin scale may be extracted from the residuals after lubricating oil has been extracted in many of the Russian petroleums.

Some notes on a new oil basin near the mouth of the Embla river have appeared. †

Petroleum in Turkey.—A. Adiassevich ‡ gives some notes on the occurrence of oil on the coast of the Sea of Marmora around Ganos, Hora, Sharkeni, and Gemlik. Several wells have been sunk by hand, and small quantities of oil have been found, as well as gas. A map of the district is given, showing the position of the wells, productive and barren, and of the localities where indications of oil were found.

Petroleum in Canada.—J. D. Noble § describes the Canadian oil industry, giving an account of the oil-producing region, the boring plant, the system of storage tanks, the method of pumping the wells, the geology of the oil, and other matters.

Petroleum in Wyoming.—In Bulletin No. 3, issued by the University of Wyoming, W. C. Knight describes the oil-fields of Crook and Uinta counties. The paper is illustrated by maps and sections, and the results of tests of samples of oil are appended.

Petroleum in Algeria.—H. Neuburger ‖ deals at considerable length with a geological investigation of the Oran oil basin in Algeria, which, in his opinion, promises considerable developments. The various basins are described in detail.

Petroleum in Japan.—S. Takano ¶ gives some notes on the present situation of the oil industry in Japan. The oil-fields extend from Torinosa in the south to Hokkaido in the north, but Echigo is the only province where oil is worked to any extent, 90 per cent. of the total being produced in that district. The daily production is about 4000 barrels, and most of the oil is of the methylene series, like the Russian and Californian petroleums. It gives 50 per cent. of burning oil. There are ninety-five refineries, with a daily capacity of 4214 barrels, and the industry is growing enormously.

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* *Petroleum Review*, vol. ii. pp. 282–283.

† *Ibid.*, vol. iii. pp. 269–271.

‡ *Ibid.*, vol. ii. pp. 281, 327.

§ Paper read before the Paris Petroleum Congress; *Petroleum Review*, vol. iii., Supplement, pp. 3–5.

‖ *Ibid.*, vol. iii., Supplement, pp. 47–52, 60–67.

¶ *Petroleum Review*, vol. iii. pp. 75–78.

Shin-ichi Takano [*] deals elsewhere with the chemistry of Japanese petroleums, and gives a detailed account of the various oil-fields.

Ozokerite in Galicia.—Details are published of an official Austrian report relating to the mining of ozokerite in Galicia, together with the regulations to prevent in the future the reckless "robbing" system of mining hitherto generally in use. These regulations provide, amongst other points, that the shafts shall be not less than about 65 yards apart, and at least half that distance from the boundary-line of the property. Those shaft-workings which have hitherto had hand ventilation are required to replace this by mechanical methods, and these are to yield 70·6 cubic feet of air per man per minute. There are to be two shafts or other entrances to the workings, and these must connect at the working level, and safe means must be adopted for the descent of the miners. The official report deals historically with the ozokerite industry of Galicia, the geological conditions, and the methods of mining in use.[†]

The occurrence of ozokerite is described by J. Ohly.[‡]

Asphalt in California.—A. S. Cooper [§] describes the veins in which asphalt occurs in California.

Oil Shale in Brazil.—J. C. Branner [‖] gives an illustrated account of the oil shales occurring on the coast of Brazil. They are of Cretaceous age, and the parti-coloured beds exposed along the coast are of the same age, as a rule. The Cretaceous strata rest on crystalline rocks, with a bed of coarse conglomerate forming the base of the series, except at one place in the State of Sergipe, where rocks of Palæozoic age are intermediate. One company started work on the Marahu deposits, but on too large a scale, and failed accordingly, and no other attempts have been made to work them. The thickness of the beds ranges from 100 to 300 feet, and in many cases the shale gives 20 to 45 per cent. of volatile matter on distillation.

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[*] Paper read before the Paris Petroleum Congress; *Petroleum Review*, vol. iii., Supplement, p. 53.

[†] *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. p. 201.

[‡] *Mining and Scientific Press*, July 7, 1900.

[§] Bulletin, No. 16, Californian State Mining Bureau, December 1899; *The Mineral Industry*, vol. viii. pp. 53–54.

[‖] *Transactions of the American Institute of Mining Engineers*, August 1900.

VI.—*NATURAL GAS.*

Natural Gas in Ontario.—E. Coste[*] gives an account of the discovery and occurrence of natural gas in Ontario. The first well of importance to strike the gas was at Ruthven in January 1889. Since then a large number of wells have been bored, and the logs of a considerable number of them are given. Only one well has reached the Trenton limestone, and most of the gas comes from the Guelph limestone and the Oriskany sandstone. The geology and the origin of the gas and gas-yielding strata are dealt with at some length, and it is shown that water-pressure alone is not sufficient to account for the high pressure at which the gas is found.

Natural Gas in Italy.—R. Nasini and R. Salvadori[†] give analyses of the various gases which are evolved, together with the saline waters and petroleum, from the springs of Salsomaggiore. The gases, which burn with a luminosity about equal to that of ordinary coal-gas, consist for the most part of methane and ethane, with varying and, in general, small proportions of unsaturated hydrocarbons, nitrogen and carbon dioxide.

Natural Gas in the United States.—The annual report of the United States Geological Survey on the production and consumption of natural gas, which has just been compiled by F. H. Oliphant,[‡] presents some very interesting features, inasmuch as it embraces a comprehensive survey of the gas-producing fields, a discussion of the evidence that the natural supply is rapidly becoming exhausted, and some statistics concerning the extent to which natural gas is utilised as fuel by the iron and steel industries. The total value of the natural gas produced in the United States last year was £4,004,973.

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[*] *Journal of the Canadian Mining Institute*, vol. iii. pp. 68–89.

[†] *Gazzetta Chimica Italiana*, vol. xxx. i. pp. 281–296.

[‡] *United States Geological Survey, Twentieth Annual Report*, Part vi. pp. 203–222.

The Appalachian fields supplied 60 per cent. of this total, and the Lima fields in Indiana 37 per cent. The total number of wells in operation at the close of the year was 9333.

The value of this fuel produced and sold last year was about £4,000,000, against £3,100,000 in 1898. To some extent the increase thus shown is due to an increase of price and the securing of more complete records than those of previous years. Mainly, however, it represents an enlargement of the quantity utilised. The new sources of supply opened up during last year, chiefly in south-west Pennsylvania and West Virginia, were few, and the pressure from the older ones was diminished. The increased delivery was secured only by the laying down of fresh pipes and a better utilisation of the existing means of supply. The report states that last year natural gas was used as fuel in 13 iron mills, 63 steelworks, 196 glassworks, and 3947 other manufacturing establishments.

G. E. Walsh * discusses the diminishing natural gas supply in the United States, and incidentally mentions the apparently inexhaustible supplies at Baku on the Caspian and in Szechuen in China. In the United States, official statistics for 1898 showed there were 13,000 miles of pipe for natural gas, of which Pennsylvania contained 5354 miles, and Indiana 4399 miles. At the present time the reserves of gas are still enormous, but the supply is undoubtedly waning, though economy has been exerted in nearly all directions. In Indiana the pressure has fallen from 325 lbs. to 195 lbs. in the last ten years; but new wells have maintained the supply, mostly from the Trenton limestone. In Pennsylvania the gas boom reached its height in 1888 when the value of the gas used was given as 20,000,000 dollars, but this fell to 6¼ million dollars in 1897. In Ohio the supply has rather increased owing to the opening up of fresh districts, noteworthy amongst which is Fairfield County with a pressure of 800 lbs. in wells reaching 2000 feet in depth. Elsewhere in this State the pressure has fallen from 450 to 30 lbs. between 1888 and 1897. West Virginia is rapidly developing her resources, and Canada is a formidable competitor.

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* *Cassier's Magazine*, vol. xviii. pp. 58–64.

VII.—*ARTIFICIAL GAS.*

The Energy in Fuel Gas.—In a recent article* the energy in various forms of fuel gas is discussed. The composition and calorific value is given as follows:—

	Carbon Monoxide.	Hydrogen.	Incombustible.	Calories.
Generator gas .	23	10	67	28
Dowson . .	23	19	58	36
Wilson . .	27	13	60	...

In ordinary generator gas about two-thirds of the energy of the coal is present in the gas as chemical energy, and the remaining third is present as heat, which is, however, practically lost, as the gas cannot be used in its highly heated state under ordinary circumstances. Much of this heat is also wasted in radiation. Steam is, therefore, passed into the incandescent fuel, and by its decomposition absorbs a large proportion of the otherwise wasted heat, and renders it available in the chemical energy of the resultant gas. Equally good results would be obtained if a pure supply of carbonic anhydride were available to replace the steam, and the fuel used for steam-raising would then be saved. But the ordinary products of combustion contain too much inert nitrogen for satisfactory use, and the nitrogen percentage increases to such a degree that ultimately the gas will not burn.

In a discussion on the economical utilisation of fuel, W. Kent † deals with the various forms of gaseous fuel, including blast-furnace gas, producer gas, water gas, enriched water gas, and gas made in retorts and in coke ovens. Numerous quotations and extracts from recent publications are given.

Water Gas.—J. Körting ‡ compares water gas with other combustible gases. The author first gives the composition of ordinary producer gas, and then that of the so-called "power" or mixed gas. These are stated as follows:—

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* *Engineer*, vol. xc. p. 355.

† *The Mineral Industry*, vol. viii. pp. 124–157.

Zeitschrift des Vereines Deutscher Ingenieure, vol. xliv. pp. 1301–1308, 1345–1348, with four illustrations.

	Producer Gas.	Mixed Gas.
	Per Cent.	Per Cent.
Carbon monoxide . . .	23 to 30	23 to 27
Carbon dioxide . . .	2 „ 7	6 „ 7
Nitrogen	50 „ 65	47 „ 52
Hydrogen	2 „ 6	17 „ 18
Methane, &c.	Small quantities	0·5 „ 2·0

Water gas is the gas that results when steam alone, without any admixture of air, is passed through red-hot fuel. The water gas used in practice has about the following composition :—

	Per Cent.
Carbon monoxide	40
Carbon dioxide	3 to 7
Hydrogen	50
Nitrogen, &c.	3 to 6

Analyses of ordinary illuminating gas and of coke oven gas are also given, and the author then passes to a consideration of the methods of manufacture and utilisation of water gas, and of the other gases referred to. Their calorific powers are passed in review, and finally a series of deductions are drawn. Water gas, the author thinks, cannot commercially replace "power" or mixed gas if it is a question of producing a gas for power purposes only; but if it is not a question of this, but of producing very high temperatures for commercial purposes, the water gas occupies the premier position. If only low temperatures are required, then the mixed gas has again the advantage, especially as by the use of blast that has been preheated the temperature attained can be raised very considerably. For lighting purposes in towns, illuminating gas is still the best, but, on the other hand, water gas plants can be considered excellent additions to those for the manufacture of ordinary illuminating gas under conditions which the author enumerates.

The Coyne Gas Producer.—An illustration of a new type of gas producer, devised by J. Coyne, has appeared.* The apparatus consists of a duplicate chambered retort, the base of which is immersed in a tank of water, thus forming a seal, the water being kept at the proper level by inlet and outlet pipes. The body of the retort consists of an outer metallic and inner refractory shell, with an intervening air space, which prevents radiation of heat. Partially inserted in the base of each chamber is a spherical perforated fire-grate, with conical projections on the exterior, and conical openings to the interior. Gas, air, steam, and oil may be conveyed to the interior of this blast-chamber grate through hollow journals. Its lower part is immersed in the water-seal or tank. These fire-grates are surrounded by tuyere pipes in order to keep the base of the retort cool, and are supported by friction rollers, which relieve the weight on the hollow journals, on and by which they are intermittently rotated, thus agitating and keeping open the base of the fuel charge. In the bottom of the water-seal tank is an opening through which the grates may be removed from the retort. At the top of the retort are two bell-valved conduits for receiving and delivering the solid fuels (coal and coke) to either combustion chamber. Properly arranged pipes fitted with reversing valves connect the chambers, and convey the gas and air blasts in either direction, provision being made for introducing a flue cleaner to remove carbon adhering to the gas pipes.

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* *Colliery Guardian*, vol. lxxx. p. 118.

VIII.—*COAL-MINING.*

Deep Boring.—The Fourteenth Congress of Boring Engineers was held at Frankfort-on-the-Main in September 1900.* E. Naumann discussed the greatest depths attained in mining and boring, and the results obtained therefrom. J. Baszanger explained the cause of the recent rise in the price of carbon, diamond, and bort used for boring purposes. E. W. Wolski described a new friction coupling for use with boring plant. H. Gothan gave an account of a magnetic needle and clockwork arrangement for determining the dip of strata in bore-holes. Other papers by E. Przibilla and by F. Steiner dealt with recent progress in the art. The committee on a standard screw gauge for casings also presented a report, referring to the thickness and dimensions of casings and the threads for tool rods.

S. Trop † describes various means of excluding water from oil wells by cement plugs and packing rings of various forms in the lining.

A. Fauck ‡ briefly describes the different forms of apparatus for sinking wells, and advocates his own system of rapid but short strokes, and other improvements.

Bennett H. Brough § describes the different instruments used for determining the verticality of boreholes. The article is one contributed to a new paper entitled *Boring and Drilling*, which, as its title indicates, is devoted to that branch of industry, and it contains many illustrations of new devices.

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* *Boring and Drilling*, vol. i. pp. 57–78; *Petroleum Review*, vol. iii. pp. 247, 278.

† Paper read before the Baku Technical Society; *Petroleum Review*, vol. iii. pp. 221–222.

‡ *Ibid.*, p. 74.

§ *Boring and Drilling*, vol. i. pp. 13–14.

Some particulars are given * of the boring on the Brewood and Stretton estate in the northern part of the South Staffordshire coalfield. The depth attained was 2034 feet, of which the last 277 feet were in the coal measures.

Shaft Sinking.—R. Sutcliffe † describes a method of sinking shafts by machinery devised by himself. Practically, the machine has some resemblance to a Stanley heading machine arranged to cut vertically. The chief part of the machine is a cutting barrel, 19 feet 10 inches in diameter, 13 feet high, built in segments, and provided with cutters on its lower edge to cut an annular groove. The core is subsequently blasted out. The barrel is driven by vertical compressed air engines with two cylinders 10 by 10 inches, and the total weight of the machine is about 25 tons, but no individual part exceeds 35 cwt., so that it can easily be taken to pieces. It has been used for sinking about 30 yards at a depth of 100 yards. The advantages of draining wet ground by advance boreholes is referred to in connection with the use of this machine for sinking.

J. Keen ‡ gives some additional notes on the progress of the Maypole sinkings near Wigan.

G. Peace § gives some brief notes on the sinking of the No. 3 Nook pit to the Trencherbone seam at Astley. It is sunk 707 yards, and took 41 months. A detailed section is appended.

G. C. McFarlane || describes a method for sinking through wet ground. Two boreholes are sunk, one in the place where the shaft is to be sunk, and then they are enlarged at the bottom by expanding cutters so as to open one into the other. Water is thus allowed to flow from the bottom of the shaft, and is pumped through the other borehole.

A new shaft is being sunk by the Péronnière Mining Company near St. Etienne, to cut the Rive de Gier seam at a depth of 3000 feet. The shaft is 14½ feet in diameter. Sinking is conducted by a new method, which consists in working by short lifts of 12 feet, each of

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* *Boring and Drilling*, vol. i. p. 2.

† *Transactions of the Manchester Geological Society*, vol. xxvi. pp. 502–518.

‡ *Ibid.*, pp. 420–426.

§ *Ibid.*, pp. 451–464.

|| *Engineering and Mining Journal*, vol. lxix. p. 411.

which is completed, walled, and equipped before the excavation of the next one below is begun, the same men being employed successively in the different operations of sinking, walling, and setting the guides. The rate of progress is about 20 yards a month.

One of the most remarkable mining exhibits at the Paris Exhibition is the model of No. 5 pit of the Bruay Colliery. There are two shafts, 4·2 metres wide and 355 metres deep, 47 metres apart, equipped with machinery of the latest type. The Company is one of the most important in France, its daily output being 5900 tons from eight shafts, all of which have been sunk by the Chaudron process.

K. Hoftich * describes the process of sinking a shaft at Sollenau, in Lower Austria, to reach a seam of lignite at a depth of 672 feet. Special difficulties were encountered, more particularly in traversing a bed of quicksand 22 feet in thickness at a distance of 510 feet below the surface. The method adopted was to employ a wrought-iron caisson made of plate driven into the quicksand, and then timbering.

F. H. and W. Poetsch † describe at considerable length the Poetsch system of shaft-sinking. The subject is dealt with historically, the earlier experiments and practical applications of the process being first described. Its first application in practice was at the Archibald brown coal mine near Schneidlingen. The freezing machine was set to work on July 8, 1883. By the end of September the shaft had been carried through the 13-foot bed of quicksand that had to be penetrated, and the work was completed. This piece of work incidentally showed that the freezing solution must not be made colder than – 20° C. One of the valves broke when struck with a hammer, and the solution escaped. The temperature of the sand sank to – 19° C., the air temperature in the shaft being then – 6°. The second application of the method was made in 1884 at the Centrum colliery, near Königs-Wusterhausen, about thirty-five yards of sand, mostly quicksand, or sand of a very watery character, having to be penetrated. This too was successful. The average cost of the shaft was about £95,8s. per yard. Other places at which this process has been used are the Max No. I. colliery, near Michalkowitz in Upper Silesia; the Emilie colliery, near Hennersdorf-Finsterwalde; the Charbonnages de Houssu at Haine Saint Paul in the Belgian Province of Hennegau; and the Jessenitz mine in Mecklenburg-Schwerin. Full details are given in each case as to the difficulties that had to be overcome, and the general procedure

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* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. pp. 297–300.

† *Ibid.*, pp. 189–192, 207–212, 223–224, and 235–237, with plate.

employed. The difficulties at the Houssu colliery were of an exceptionally annoying character, and by no means merely those due to the ordinary geological conditions. It was found, amongst other things, that care must be taken to get rid of all surface water from the immediate vicinity of the shaft. The question of cost is also dealt with.

The successful sinking by the freezing process of the shaft belonging to the Willem Sophie Colliery Company at Heerlen, in Dutch Limburg, is described.*

M. E. Clere † describes the construction of iron tubbing rings used at a number of French and Belgian collieries. A number of illustrations are appended.

Marcel Habets ‡ deals with the use of concrete for lining shafts, and for other purposes in mines.

Winding Appliances.—Since W. Galloway described the compound winding engines at Llanbradach Colliery the use of the compound winding engine has received much attention in Germany, and several engines of this type have been constructed. That furnished to the Scharnhorst Colliery is fully described by F. Schulte.§ It is designed for a useful load of 4·4 tons, a depth of 600 yards, and an average winding-rope velocity of 33 feet a second, a spiral drum being used.

Valuable work in winding from great depths was done by S. B. Whiting, who introduced a system of winding with round ropes by means of drums similar to those used for cable tramways. Fraser and Chalmers have overcome the difficulty experienced with this system, due to the unequal wear of the grooves in the drums, by using Walker's patent differential rings on the drums instead of the common wood filling. The variable dead weight of rope when winding from different levels has been obviated by introducing a tail rope. In this way identical engines can be used for any depth of shaft up to the limit of strength of engine and rope. The use of a cross compound Corliss engine, with one high pressure and one low pressure cylinder, is advocated with this system of winding. There is a modification of the Whiting system, which in some circumstances is preferable. The engine has one large drum kéyed on to the crank shaft. One rope is fastened to one end of this drum and the other rope to the other end, so that one rope winds on while the other winds off. One rope is taken directly to the headgear, while the other is first laid over a take-up gear, consisting of a sheave placed on a carriage and of winding machinery for shifting this carriage along its track. This gear is similar to that used in the Whiting system. The disadvantage of the drum hoist is that it cannot be used for a greater depth than that for which its drum is built. On the other hand, it has the advantage that, should an accident occur to one rope, only the skip on that rope would be dropped, and not both, as would be the case in the Whiting hoist.*

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* *Bergbau*, July 23, 1900.

† *Mémoires de la Société des Ingénieurs Civils de France*, 1900, pp. 549-560.

‡ *Revue Universelle des Mines*, vol. l. pp. 32-48.

§ *Glückauf*, vol. xxxvi. pp. 557-561.

Illustrations are given elsewhere † of Whiting's arrangement for winding. The rope is led round two pulleys, the arrangement being like that of a cable tramway. Each pulley is furnished with Walker's rings.

Illustrations are given ‡ of the Brucksch reversing gear as fitted to the winding engines at the Luise lignite pit, Nieder-Schönbrunn, in the Görlitz district.

Shortly before the outbreak in China the Gutehoffnungshütte at Oberhausen constructed a winding plant for a colliery in the neighbourhood of Tongschau, about thirty-seven miles from Tientsin.§ This is now illustrated and described. It is capable of winding ninety tons of coal per hour from a depth of over 560 yards.

J. Gregory || and J. T. Stobbs describe the Koepe system of winding, which has been in use for seventeen years at the Sneyd Colliery, Burslem. A. Ehrlich ¶ urges the advantages presented by the Koepe system of winding over the ordinary winding drum.

G. B. Stones ** describes the hydraulic cage-loading and unloading apparatus at Cadeby Colliery. The output at present is about 1800 tons a day, and it was anticipated that this would be increased to 5000 tons a day, drawn from two shafts, when the colliery was fully developed. The cages have four decks, each carrying two corves, containing an average of 10 cwt. each. The decks are loaded and unloaded simultaneously, the top deck by manual labour, the others by

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* "Hoisting Engines and Appliances." Catalogue No. 2. Fifth Edition. 1900. (Chicago and London: Fraser and Chalmers.)

† *Iron Trade Review*, August 16, 1900, p. 18.

‡ *Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xlviii. pp. 145–146.

§ *Stahl und Eisen*, vol. xx. p. 997, with two illustrations.

|| *Transactions of the Institution of Mining Engineers*, vol. xviii. pp. 450–457.

¶ *Zeitschrift des Vereines deutscher Ingenieure*, vol. xliv. pp. 675–680.

** *Transactions of the Institution of Mining Engineers*, vol. xviii. pp. 478–482.

hydraulic machinery. The time occupied in loading and unloading is about five seconds. In this connection reference may be made to the mechanical caging appliances at the Commentry Colliery described by Martinet.[*] The tubs are delivered by gravity in sets of three in front of the cage, on to which they are pushed by an arm projecting from an endless chain between the rails. The chain is driven by rack gear from a steam cylinder.

The caging appliances at the Boisgelin shaft of the Dourges collieries are illustrated.[†] Two deck cages, each carrying four tubs, are used, and the floors are tilted as they settle on the keps, so that the loaded cages can run in as the empties run out, or *vice versâ* at the surface.

Details have been published[‡] of a visit to the Neuville pit of the Grand-Mambourg-Sablonnier Colliery, Belgium, a description being given of the Reumax safety appliance for the prevention of over-winding, and other equipments.

In Satta's safety catch an endless rope runs at exactly the same speed as the rope holding the cage, and parallel with it. This rope bears a wedge. Attached to the cage is a roller. If the winding rope breaks, the cage falling causes the roller to mount the wedge; this being attached to the rope above mentioned, is then dropping at the original speed only. The wedge in this way jams the roller and the cage, and brings the roller to a stop.[§]

Winding Ropes.—Some interesting statistics regarding the winding ropes in the Dortmund coalfield are published.[||] From 1872 to the end of 1899, twenty-eight years, of the 6461 winding ropes installed, the sudden fractures during use were as follows:—

Of 826 cast steel flat ropes	48 or 5·81	per cent.
Of 147 iron flat ropes	19 or 12·93	,,
Of 97 aloe flat ropes	7 or 7·22	,,
Of 8 hemp flat ropes	0 or 0	,,
Of 4467 cast steel round ropes	83 or 1·86	,,
Of 881 iron round ropes	105 or 11·95	,,

Thus, of the 6461 winding ropes, 262, or 4·06 per cent., broke suddenly. The proportion fell from 19·30 per cent. in 1872 to 0·52 per cent. in 1899, the best result recorded.

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[*] *Comptes Rendus Mensuels de la Société de l'Industrie Minérale*, 1899, pp. 168–170, with two plates.

[†] *Colliery Guardian*, vol. lxxx. p. 497.

[‡] *Ibid.*, vol. lxxix. pp. 1026–1027.

[§] *Oesterr. Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. p. 318.

[||] *Glückauf*, vol. xxxvi. pp. 580–581.

Underground Haulage.—The use of pit ponies and horse haulage is dealt with by F. Povey-Harper,* questions of feeding, shoeing, stabling, and the cost being reviewed.

J. Fox Tallis † gives a number of dimensioned drawings of twenty-seven trams used in the Welsh coalfields, and in many cases gives sections of the rails used at the collieries. A suggested design is also given as a standard. In tabular forms are given the leading dimensions and other particulars of the trams, rails, and sleepers. The ratio of tare to weight carried in the trams ranges from 23·9 to 36·5 per cent.

W. D. L. Hardie ‡ describes the endless under-rope haulage at Lethbridge colliery with the aid of a plan of the workings and illustrations of the various mechanical details.

W. Smith § describes the Priestman oil engine used for underground haulage and pumping at the Jellieston Colliery, Scotland.

Heimann ‖ describes the mechanical haulage in the Upper Silesian collieries. Details are given of the chain haulage at seven collieries, in which the lines varied from 400 to 1850 metres in length and the cost per ton-kilometre from 3·98 to 10·8 pfennig; of the rope haulage at seventeen collieries, in which the lines varied from 560 to 2200 metres in length and the cost per ton-kilometre from 1·96 to 14·7 pfennig; and of the locomotive haulage at three collieries, in which the lines varied from 450 to 1250 metres in length and the cost from 7·7 to 8·6 pfennig.

The various mechanical methods of haulage in use in the levels of the mines and collieries of Upper Silesia are described by Heimann.¶ These include the various kinds of chain and rope traction, and also those in which electric or benzine engines are in use.

Hein's releasing appliance for rope clips is illustrated.** Sickle-shaped guard-irons depress the clip and free it from the rope.

The system of electric mine-haulage which has greatly increased the output of the Eureka collieries in the Windber district in the United States, is described by A. S. M'Allister.†† In the case of one mine, the work was first developed by mule haulage in the cross-headings, combined with a rope hoist in the main headings, the entrance having a dip of 2·5 per cent. for 3000 feet. Using eight mules and eight drivers in addition to the hoist, the daily output of the mine was 200 tons, at a cost of about 5d. per ton. Using two electric mine locomotives in place of the mules and hoist, the daily output has increased to 1000 tons, at a cost of less than 0·4d per ton.

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* *Journal of the British Society of Mining Students*, vol. xx. pp. 126–130.

† *Proceedings of the South Wales Institute of Engineers*, vol. xxii. pp. 37–63.

‡ *Transactions of the Institution of Mining Engineers*, vol. xviii. pp. 335–339, with two plates.

§ *Ibid.*, vol. xviii. pp. 396–400.

‖ *Glückauf*, vol. xxxvi. pp. 449–456.

¶ *Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xlviii. p. 18.

** *Colliery Guardian*, vol. lxxix. p. 834.

†† *Engineering*, vol. lxx. pp. 291–293; *American Electrician*, 1900, pp. 318–320.

The endless rope haulage at the new slope No. 3 Pratt coal-mine at Ensley, Alabama, is described.* The rope runs at 158 feet per minute, and the loaded trams weigh 4476 lbs.

J. H. Bowden † describes the compressed air locomotive haulage plant of the Susquehanna Coal Company at Glen Lyon, Pennsylvania. The plant comprises one Norwalk three-stage compressor, 12½, 9½, and 5 inches diameter of air and 20 inches diameter of steam-cylinder, all 24 inches stroke; capacity at 100 revolutions, 296 cubic feet of free air per minute, compressed to 600 lbs. per square inch. A main pipe, 5 inches diameter, 4380 feet long, with five charging stations in No. 6 shaft, and a branch of 3-inch pipe, 3100 feet long, with three charging stations, in No. 6 slope. These pipes on each line charge a Porter compressed air motor with 7-inch by 14-inch cylinders and four 24-inch drivers, weighing about 8 tons, with a tank capacity of 130 cubic feet of air at 550 lbs. pressure in the main tank, reduced to 160 lbs. in the 8-inch auxiliary tank of 4·2 cubic feet capacity, supplying the cylinders. The No. 6 shaft run averages 4000 feet each way on grades of ½ to 2¾ per cent., and averaging close to 1 per cent. in favour of the loaded cars. The No. 6 slope run averages 2100 feet, with nearly the same grades. The mine cars weigh 2800 lbs. empty, and about 9800 lbs. loaded, and are hauled in trips of twelve to twenty, averaging about fifteen cars. The shaft motor now hauls about 355, and the slope motor 320 cars per day of ten hours, replacing in the shaft seventeen mules and in the slope fifteen mules, or, in all, thirty-two mules, against twenty-seven replaced in 1896. Full particulars of the work done and the costs are given.

J. H. Ronaldson ‡ gives a general account of the transmission of power by compressed air.

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* *Iron Trade Review*, August 30, 1900, pp. 11-13; *Colliery Guardian*, vol. lxxx. p. 605.

† *Transactions of the American Institute of Mining Engineers*, Canadian meeting, August 1900.

‡ Paper read before the New South Wales Chamber of Mines, June 1900; *Colliery Guardian*, vol. lxxx. pp. 547-548.

Electricity in Mines.—H. Louis [*] has published a series of articles in which details are given of various examples of the application of electricity to mining. The subjects dealt with are classified under the following heads:—(1) Lighting; (2) shot firing by electricity; (3) applications of magnetic properties; (4) electrical transmission of power; and (5) special mining machinery.

J. Libert [†] discusses the employment of electricity in mines at considerable length, and traces its evolution since the last Paris Exhibition. Especial reference is made to Belgian practice. The paper forms one of the reports submitted at the Congress on Mining and Metallurgy held at Paris.

S. F. Walker [‡] describes and illustrates various applications of electricity in British collieries. Hauling, coal-cutting, pumping, and lighting are described with the aid of numerous illustrations, and the generating plant is also dealt with in some detail.

S. F. Walker [§] discusses the problems involved in running collieries entirely by electricity from one centre, and shows the advantages of that system.

W. Müller [‖] describes at considerable length, and with the aid of many illustrations, the electric hauling and winding machinery in use in the Ruhr district. An abridged translation has appeared.[¶]

E. Schulz [**] describes a portable type of electro-motor protected from dust and dirt.

A detailed description of the central electric station for light and power at the Margarethe colliery at Sölde, in Westphalia, has been published. The station supplies the village as well as the colliery.[††]

Hand-Boring Machines.—Comparative experiments [‡‡] at the Reden colliery with hand-boring machines gave the following results:—

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[*] *Mining Journal*, vol. lxx. pp. 604, 634, 664, 697, 778, 796, 825, 875, 902, 925, 941, 973.

[†] *Bulletin de la Société de l'Industrie Minérale* (advance proof).

[‡] *Engineering Magazine*, vol. xix. pp. 713–727, 847–866.

[§] *Journal of the British Society of Mining Students*, vol. xxii. pp. 116–125.

[‖] *Glückauf*, vol. xxxvi. pp. 341–352.

[¶] *Iron and Coal Trades Review*, vol. lx. pp. 940, 1037, 1081.

[**] *Glückauf*, vol. xxxvi. pp. 405–406.

[††] *Ibid.*, pp. 393–394.

[‡‡] *Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xlviii. pp. 104–150.

Number of Trials.	System.	Time of Setting up.	Speed per Minute.	
			Without Setting up.	With Setting up.
	In coal:—	Minutes.	Centimetres.	Centimetres.
49	Forster	5·0	9·32	6·35
52	Leyendecker. . .	4·6	14·88	11·20
9	Elliot	4·3	19·70	16·60
3	Blitz	10·8	10·24	9·77
	In shale:—			
13	Forster	5·3	6·43	4·78
8	Leyendecker. . .	5·0	7·32	5·35
9	Elliot	4·2	9·09	6·57
	In sandstone:—			
19	Forster	5·6	2·37	2·03
5	Leyendecker. . .	5·0	4·38	3·59
10	Elliot	4·5	2·69	2·39

The Elliot machine gave the best results both in coal and shale.

R. Martin * describes a form of drill for boring front and flank holes from 50 to 70 feet in advance.

Coal-cutting Machinery.—The conditions adverse to the use of coal-cutting machinery in England, and favourable to their use in America, are stated † in a letter from an American source. In the United States pillar-and-stall is the rule, and machines have developed and multiplied to suit that system in preference to long-wall. There are, nevertheless, several long-wall machines in use.

J. W. Chenhall ‡ describes the Cambria coalfield in Wyoming, and the plant employed in the collieries, with special reference to the coal-cutting machinery. Jeffrey cutter bar machines and Ingersoll-Sergent machines are used, and particulars of the work done by them are given.

At the Mining and Metallurgical Congress at Paris a paper on coal-cutting machines in the United States of America was contributed by A. Bachellery.§ Machines of the various types in use are described, and also the application of electric driving power.

E. W. Parker || gives his usual statistics as to the increase of coal-

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* *Transactions of the Institution of Mining Engineers*, vol. xix. pp. 69–70.

† *Colliery Guardian*, vol. lxxx. p. 190.

‡ *Minutes of Proceedings of the Institution of Civil Engineers*, vol. cxxxix. pp. 323–333.

§ *Bulletin de la Société de l'Industrie Minérale* (advance proof).

|| *United States Geological Survey, Twentieth Annual Report*, Part vi. pp. 295–393; *Iron and Coal Trades Review*, vol. lxi. p. 781.

cutting machinery in the United States. The number of machines used in 1899 was 3125, and 43,963,933 tons of coal were produced, an increase of about 11½ million tons over the previous year.

Timbering in Mines.—J. Dickinson [*] discusses the question of pit props and their setting, showing that the length of a prop does not affect its strength within the usual limits of ratio of diameter to length, and that divided opinions are still held as to the direction or angle at which props should be set. The supply of timber and the use of tubular steel props are also referred to and discussed.

The Balmer pit prop consists of two cast iron cylinders, of which the lower is filled with loose packing and the upper part telescopes into it. Holes in the side of the lower cylinder allow some of the packing to be removed, so that the prop can shorten itself.[†]

S. J. Bridges [‡] gives some particulars showing the advantages of Hepplewhite's tapered props.

The methods of timbering in use at the Courrières collieries near Lens are described and illustrated.[§] Each worker at a face has a number of iron bars 1⅜ inch square and 4¼ feet long, which he uses as roof bars, and keeps them in advance of the last set of props.

Mine timbering in Germany is discussed by F. H. Probert,[‖] especially in view of Californian practice.

W. E. Sanders [¶] describes the methods of timbering used in the Western United States, chiefly in shafts and working places of metal mines.

O. Chanute [**] gives details of the present practice of preserving timber, chiefly as applied to railway sleepers.

David J. Evans,[††] in a paper read before the Indiana Mining Institute, describes various ways of cutting and placing timbers to secure the best results.

Explosives and Blasting.—At the Paris International Congress on mining and metallurgy several papers in connection with explosives were read.* Delafond deals with the regulations for the use of safety explosives in France, where grisoutine and grisoutite are mainly used, and the size of the charge and the depth of the tamping are prescribed. V. Watteyne and L. Denoel give an account of Belgian practice, where a larger number of the ammonium nitrate explosives are in use. In that country much use has been made of wedges and other breaking-down appliances in substitution for explosives, and drills of various kinds are extensively employed. H. Le Chatelier summarises the various reports of official and other trials and experiments on the construction of underground and surface magazines for high explosives made at Servan and Blanzy.

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[*] *Transactions of the Manchester Geological Society*, vol. xxvi. pp. 476–484.

[†] *Transactions of the Institution of Mining Engineers*, vol. xviii. pp. 431–432.

[‡] *Iron and Coal Trades Review*, vol. lxi. p. 835.

[§] *Ibid.*, vol. lxi. pp. 571–572.

[‖] *Transactions of the American Institute of Mining Engineers*, Washington meeting, 1900.

[¶] *The Mineral Industry*, vol. viii. pp. 715–743.

[**] *Journal of the Western Society of Engineers*, vol. v. pp. 100–126.

[††] *Mines and Minerals*, vol. xxi. pp. 39–40.

The testing of explosives for mining purposes at the Government testing station is dealt with by Capt. M. B. Lloyd,† H.M. Inspector of Explosives, and the special test now in use is described. It is pointed out that no explosive can be made absolutely safe under all conditions, but visible flashes from permitted explosives are not necessarily dangerous. Certain suggestions are made regarding the future conduct of the tests.

S. Heyda ‡ describes some comparative experimental tests in practice of dynammon No. 1, and compressed blasting powder. The former consists chiefly of ammonium nitrate, to which is added easily combustible organic substances. The dynammon is made of two sorts, one of which, termed fire-damp dynammon, is intended for use in fiery collieries, and the other, of equal strength, is that now under consideration. It does not freeze, and is entirely uninfluenced by friction or percussion. It can be struck with a heavy hammer, and can be put into an open fire without exploding. On being exploded, it gives very little smoke, and is officially permitted to be sent as ordinary freight by any goods train. It was found to be more than twice as powerful as the compressed powder.

J. Jicinsky describes an automatic door for underground stores for explosives, § which may be used to comply with the Austrian mining regulations.

F. Pospíšil ‖ considers the question of keeping large quantities of explosives underground, and deals with the results obtained by a

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* *Bulletin de la Société de l'Industrie Minérale*, vol. xiv.

† Report on the Working of the Government Testing Station for Explosives for the year 1899.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. pp. 269–274.

§ *Ibid.*, vol. xlviii. pp. 345–346.

‖ *Ibid.*, pp. 133–136, 156–159, with 10 illustrations.

French Commission on this subject. The subject is dealt with fully, and it is shown that it is undesirable to allow a magazine under ground to contain more than 2 cwt. of explosives. These are to have two open-work doors to allow of ventilation, and are to be well out of the way of any possible interference with the ventilation should an explosion result.

A memoir by R. Mewes[*] on the efficacy of explosives is published.

The Meinhara percussion igniter is an arrangement by which it is intended to avoid danger in fiery mines, in which fuses can still be used, from the explosion of the detonator used to ignite the fuse. A tube is employed that can be placed over the detonator. In this tube is a spring surrounding a sort of piston rod. When a ring outside the apparatus is pulled and then let go, this rod is forced back by the spring against the detonator, and explodes this inside the tube. Smoke issuing through holes in the tube shows if the fuse has fired properly. The apparatus is of very small dimensions, being only about 7½ inches in length, and can readily be put in the pocket, with, say, 100 detonators. These are covered with wax to render them water-tight in the mine, and, packed in boxes, do not take up more space than would a watch. The fuse requires no preparation.[†]

A description has been published[‡] of a French device by which a fuse may be safely fired in a fiery mine.

Methods of Working Coal.—At the Paris International Congress of Mining and Metallurgy three long papers were included on the conditions of mining at great depths. They were by L. Poussigue,[§] S. Stassart,[‖] and J. Hrabak.[¶] Of these, the second by S. Stassart dealt more particularly with Belgian practice, and considers in detail the arrangements of five of the deepest collieries in that country. The increase of temperature involves greatly increased ventilation, and at the same time the air must be dry. Winding may be done at depths to 1630 yards in one lift with moderate loads at high speeds, but the author is strongly in favour of the flat aloe-fibre rope in preference to wire ropes. Pumping, ventilation, and cooling the air are also considered.

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[*] *Dingler's Polytechnisches Journal*, vol. cccxv. pp. 408–412.

[†] *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. pp. 197–198, with an illustration.

[‡] *Mines and Minerals*, vol. xx. p. 539.

[§] *Bulletin de la Société de l'Industrie Minérale*, vol. xiv. pp. 193–374.

[‖] *Ibid.*, pp. 375–479.

[¶] *Ibid.*, pp. 135–192.

L. Poussigue's paper covers 180 pages, and contains numerous tables and illustrations, the mathematical side being also greatly developed. Questions of ventilation and winding absorb most of the space. The following are the conclusions arrived at on the subject in question:—Two circular shafts of large diameter should be sunk; pit-head gear of suitable height with facilities for unloading rapidly should be erected; the frame should be of steel; round tapering steel ropes should be used; the drums should be either conical or spiral; they should be placed one behind the other; winding machinery should consist of a couple of compound engines; effective ventilation by means of powerful fans should be introduced, and the pumping should be done by electrically driven pumps. The author believes that winding machinery is destined to undergo great changes, that the heavy rope, with all its drawbacks, is destined to be suppressed, and that when once this point is gained the true solution of the problem of working deep mines will have been attained. The only limit will be that imposed by the high temperature rendering it impossible for man to work at the depth in which it prevails.

J. Hrabak advocates conical drums and winding in two lifts or more. The winding appliances in vogue at the deepest mines are considered, and various arrangements of the winding plant are suggested.

H. M. Chance * discusses some of the problems of deep mining, especially in reference to the ventilation, and proposes to drive rooms or stalls parallel to the main haulage roads to serve as additional air ways.

W. S. Gresley † describes the various methods in use for working twin seams of coal, that is, splits of the same seam or two seams lying close together. For convenience of treatment, the subject is divided under the following heads: (1) Room and pillar, (*a*) flat and moderate dips, (*b*) steep seams; (2) modified long-wall; (3) long-wall, (*a*) flat coal and easy dips, (*b*) steep seams. A number of examples of each type are then described in detail with the aid of plans.

A method of mining coal by the use of long-wall undercutting machines for taking out the ribs or pillars left after the stalls have been driven is described by W. S. Gresley.‡

W. S. Gresley § gives some notes on the disadvantages and other features attending the withdrawal of ribs and pillars in colliery workings. Some forty points are considered, and the author advocates machine-cutting.

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* *Journal of the Franklin Institute*, vol. cl. pp. 152–155.

† *Engineering and Mining Journal*, vol. lxix. pp. 559, 589, 621.

Mines and Minerals, vol. xxi. pp. 82–83; *Iron and Coal Trades Review*, vol. lxi. p. 83.

§ *Engineering and Mining Journal*, vol. lxx. pp. 247–249.

J. T. Baird [*] describes the various systems of working coal adopted in Iowa; long-wall, pillar-and-stall, double stall, and panel breasts are all used.

G. E. Harris [†] describes the Makum coalfield in Assam, and gives some details of the method of working adopted, which resembles the South Staffordshire square work. Sides of work, 30 by 40 yards, are set off and pillared in the lower part, after which the upper part is dropped by thinning and removing the pillars.

Watteyne [‡] discusses the prevention of accidents in the shoots or passes used for delivering coal in inclined seams.

Mine Drainage.—Henry Davey [§] has written an exhaustive work, in which he divides his subject-matter into fifteen chapters, dealing respectively with the early history of the pumping engine, steam pumping engines, pumps, and pump valves, the general principles of non-rotative pumping engines, the Cornish engine, simple and compound types of mining engines, pitwork, shaft sinking through water-bearing strata, hydraulic transmission of power in mines, valve gears of pumping engines, water pressure pumping engines, waterworks engines, pumping engine economy and trials of pumping machinery, centrifugal and other low-lift pumps, and hydraulic rams. Electric pumps are not dealt with. Electricity, the author points out, is coming into use as a medium of transmission of power to underground pumps, but up to the present time it has not been largely used except for small powers. The chief difficulty has been in the application of the quick-running motor to the slow-running pump, an operation involving high-speed gearing, belts, or ropes, all of which are practically objectionable. Attempts are being made to produce a quick-running pump and a slow-running motor in order to minimise the gearing required. It is in this direction that improvements must be made if electricity is to be applied to heavy pumping.

The old Cornish engine with its pitwork has been superseded by improved types of pumping machinery. Long experience has, however, shown the value of working with engines that have a distinct pause after each stroke. Rotative engines are used to actuate heavy pitwork, but when so applied there is more vibration, more wear and tear, and consequently greater cost of up-keep than there is with non-rotative engines. The latter usually have the same speed of stroke, whatever number of strokes they may make per minute, the variation in the number of strokes being governed by the pause between the strokes. With rotative engines, on the other hand, there is difficulty in running very slowly. A pumping plant of special interest, illustrated and described in detail, is that designed by the author for the Miike Mine, in Japan. It is probably the largest pumping plant erected on one shaft. The complete plant is capable of raising 9000 gallons per minute from a depth of 900 feet, when the engines are running at six strokes a minute. This represents 58,000 tons, or 13,000,000 gallons of water in twenty-four hours. The total horse-power in water lifted is 2500.

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[*] *Mines and Minerals*, vol. xxi. pp. 126–127.

[†] *Transactions of the Manchester Geological Society*, vol. xxvi. pp. 572–590.

[‡] *Annales des Mines de Belgique*, 1900, No. I.

[§] *The Principles, Construction, and Application of Pumping Machinery.*

W. Galloway's* lecture on pumping, forming the fourth of his mining series, is published. The details of the pumps and pipes are considered, and various types of pumps are described at length, including the Cornish, Davidson, Riedler, Worthington, Moore hydraulic, Kaselowsky hydraulic, electric and other pumps.

K. Habermann † describes the Riedler express pumps. These have been designed for use with electro motors. Ordinary pumps making up to 60 throws a minute are not well suited for the very rapid movement of an electro motor, and these pumps have been designed specially to meet such a case. They can work about five times as fast as the ordinary speed, and give excellent mechanical results.

C. Wood ‡ describes the Pohle method of raising water by letting compressed air into the bottom of a range of pipes, so that as it rises and expands it lifts the water.

The Borsig § "mammoth" pump is also one of the air-lift type, and has found a somewhat extended use, particulars of which are given.

A detailed description of the underground pumping-engine at the Preussen colliery of the Harpen Company has been published by F. Schulte.‖ The description is accompanied by dimensioned drawings on large folding-plates. The engine (a compound Corliss), which has been at work for eight months, presents many points of novelty.

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* *Proceedings of the South Wales Institute of Engineers*, vol. xxi. Appendix, pp. 1–41.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. pp. 321–325, with plate.

‡ *Proceedings of the Cleveland Institution of Engineers*, vol. 1899–1900, pp. 12–28.

§ *Ingeniören*, Copenhagen, 1899, p. 196.

‖ *Glückauf*, vol. xxxvi. pp. 425–427.

C. François * describes the Kaselowsky pumping-engine at Westphalian collieries.

H. Schmerber † describes the construction of a subterranean drainage level which is to connect the lignite mines of Gardanne, near Marseilles, with the sea. The paper gives a long and well-illustrated account of methods of construction and apparatus employed.

C. Cooke ‡ gives some notes on the reopening of a flooded colliery in the Lancashire coalfield. The colliery had been worked on bad lines in the middle of the century, but was recovered about 1874 with some difficulty, due to the extensive caving and the large amount of water. After a short period the colliery was again drowned, and extensive pumping operations, followed by re-sinking under many difficulties, were again successful, but only for a year, when the water again broke it. The various operations are sketched in some detail.

The Ventilation of Collieries.—In his monograph on the conditions of mining at great depths, contributed to the Congress on Mining and Metallurgy at Paris, L. Poussigue § discusses the problems of ventilation at considerable length, and *inter alia* refers to the use of Ser and of Mortier fans running in series.

At that Congress Paul Petit || discussed the resistance opposed to air currents by regulating doors.

Comparative tests of a Rateau and a Guibal fan, under the same conditions, have been made by A. Soupart and L. Legrand of the Charbonnages Réunis de Charleroi,¶ and a table recording the results of the experiments is given. A mean of the four observations made on each of the two fans shows that the Rateau has a mean mechanical yield of 0·635, and the Guibal one of 0·445, the difference in favour of the Rateau being 0·19.

An illustration is given ** of the Mortier fan at the Bruay colliery.

H. W. Halbaum †† discusses the practicable scope or the limits

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* *Revue Universelle des Mines*, vol. xlvii. pp. 152–164.

† *Génie Civil*, vol. xxxvii. pp. 57–60, 100–102.

‡ *Journal of the British Society of Mining Students*, vol. xx. pp. 147–155.

§ *Bulletin de la Société de l'Industrie Minérale*, vol. xiv. pp. 193–373.

|| *Ibid.*, vol. xiv. pp. 481–949.

¶ *Revue Universelle des Mines*, vol. l. pp. 44–51.

** *Colliery Guardian*, vol. lxxx. p. 424.

†† *Ibid.*, vol. lxxx. pp. 315–317.

of the equivalent-orifice theory, with especial reference to the work done by the Fan Tests Committee.

Martinet [*] describes some methods of interlocking two or more ventilation doors, so that only one can be opened at a time.

F. T. Peacock [†] discusses the advantages of constructing fans so that they may be used as exhausting or forcing fans as desired. In some of the Canadian collieries the casing is made so that it can be turned; but a preferable arrangement is one shown applied to a Walker fan. In this swing doors are used to close or open the air drift and the central air inlet of the fan to the atmosphere and to the mine.

C. Connor,[‡] discussing the draining of gas from gob workings, considers the relative advantages of force and exhaust fans for this purpose.

R. Oswald [§] describes a screw fan partly immersed in water.

P. Fuchs [‖] describes recording indicators for firedamp and the velocity of air currents. Photographic apparatus is arranged to take photographs of the measuring tubes at regular intervals on a sensitised strip.

Firedamp Explosions.—Kotsowpky [¶] discusses the investigations made by himself and others on the question of firedamp in the Donetz coal basin and elsewhere in Russia, and refers to the work of the Government Commission appointed to deal with the matter. Regulations concerning safety lamps and explosives have been made.

The mine explosion at Scofield, Utah, is described.[**] It was one of the most serious disasters of modern times, causing the loss of over 250 lives.

Don Maguire [††] also describes the disaster at the Scofield mine of the Pleasant Valley Coal Company, Scofield, Utah.

J. W. Paul [‡‡] reports on the Red Ash Mine explosion in West Virginia, that occurred in March 1900, killing forty-six men; and gives elsewhere* a description of the mine and conditions existing before the accident.

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[*] *Colliery Guardian*, vol. lxxix. p. 980.

[†] Paper read before the Mining Society of Nova Scotia; *Colliery Guardian*, vol. lxxx. p. 16.

[‡] *Mines and Minerals*, vol. xxi. pp. 61–65.

[§] *Transactions of the Institution of Mining Engineers*, vol. xviii. p. 458.

[‖] *Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xlviii. pp. 12–17.

[¶] Paper read before the International Congress of Mining and Metallurgy, Paris, 1900; *Bulletin de la Société de l'Industrie Minérale* (advance proof).

[**] *Engineering and Mining Journal*, vol. lxix. pp. 552–553.

[††] *Mines and Minerals*, vol. xx. pp. 485–486.

[‡‡] *Engineering and Mining Journal*, vol. lxix. pp. 675–676.

The Lighting of Collieries.—Some illustrations of various forms of modern and other safety lamps have appeared.†

J. G. Patterson ‡ describes Howat's latest form of safety lamp, the Patterson gauze, and the Darrah-Patterson electric igniter.

J. Ashworth § deals with the failures of safety lamps while in use, and some of the disasters caused thereby. Especial attention is given to the risk of explosion in air containing fire-damp and dust in suspension.

An account is published by Fillunger || of an explosion, which was fortunately of a very slight character, and was apparently due to the internal percussion-igniting arrangement in the lamp, which was of the Wolf benzine type. The author considers that other explosions have been due to the same cause.

In the discussion which ensued on the reading of this paper Pospisil mentioned a similar case. In this instance the lamp had gone out, and there was apparently no gas in the level at this point. On relighting the lamp by the percussion attachment, a slight explosion of gas took place within the lamp, and at one part of the gauze a flame appeared radially around the lamp for a distance of about an inch. This appearance of flame was merely momentary. The author shortly afterwards went back to the same spot and tried to repeat this, but failed to do so. He has since seen a similar experience described by J. Ashworth and A. R. Sawyer. Dust, he thinks, has much to do with such explosions.¶

Fähndrich ** describes the testing station for safety lamps and the experimental mine gallery at Bismarck, in Westphalia. The paper is accompanied by dimensioned drawings of the lamp-testing apparatus employed.

The electric lamp designed by Gülcher †† for use in collieries gives

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* *Mines and Minerals*, vol. xx. pp. 537–539.

† *Iron and Coal Trades Review*, vol. lx. p. 1231, vol. lxi. p. 13.

‡ *Transactions of the Manchester Geological Society*, vol. xxvi. pp. 362, 427; *Transactions of the Institution of Mining Engineers*, vol. xix. pp. 42–47.

§ *Ibid.*, vol. xxvi. pp. 519–551.

|| Paper read before the Mining and Metallurgical Society of Moravian-Ostrau.

¶ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii.; *Beilage*, pp. 31–33.

** *Glückauf*, vol. xxxvi. pp. 445–449.

†† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. p. 450.

about double the light of a benzine lamp, and keeps alight for ten or eleven hours.

A later account of the Gülcher * electric safety lamp shows that it is an 8-volt lamp worked by a 4-celled accumulator. The weight of this lamp is about 7 lbs. This lamp will furnish light for ten or eleven hours, and the light given is twice that of an ordinary benzine safety lamp.

Rescue Appliances for Collieries.—H. Lüthgen † describes the use of the pneumatophore in cases of accident. Its value must not be exaggerated. It is very useful in a limited field.

History of Coal-Mining.—A review ‡ of the past conditions of coal-mining, and of the various Acts now in force affecting the industry in Great Britain, has recently appeared.

In a volume of 48 pages,§ J. B. Simpson has collected some interesting information on capital and labour in its relation to coal-mining during the last two hundred years. The profitableness of coal-mining is first dealt with at some length, and many quotations are given. On the whole, it is concluded that the return on the capital invested cannot exceed, and perhaps does not even reach, as much as 5 per cent. Considering that 1½ to 2 per cent. must be set aside for redemption, the profits do not appear to be very great. The changes in labour rates are then dealt with and summed up as follows:—

	1700.	1800.	1896.
Hewers' wages	1s. 2d.	3s. 0d.	5s. 1d.
Hours worked	12	12	6
Wage per hour . . .	1½d.	3d.	10d.
Hewing coal per ton . .	4d.	10·3d.	1s. 5·4d.
Selling price of round coal free on board on the Tyne . .	4s. 1d.	7s. 8d.	7s. 2d.
Wage proportion of selling price	$\frac{1}{12}$	$\frac{1}{8}$	$\frac{1}{5}$
Selling price of wheat per quarter	35s. 7d.	113s. 10d.	26s. 2d.

Diagrams are appended to show these changes, and also the increase of production.

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* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. p. 556.

† *Glückauf*, vol. xxxvi. pp. 593–595.

‡ *Engineering*, vol. lxx. pp. 73, 141, 215, 260.

§ "Capital and Labour in Coal-Mining." Newcastle-on-Tyne: 1900. A copy of the work has been presented by the Author to the Institute Library.

K. Müller[*] describes what he believes to be the first steam-engine ever used in the brown coal mines of North-West Bohemia. It was erected near Udwitz in 1813.

At a meeting of the Western Pennsylvania Central Mining Institute, F. C. Keighly read a paper on bituminous coal-mining, in which he showed that the first discovery of coal in America was made by Father Hennepin in 1669 in Illinois. The city of Pittsburg was laid out in 1764, and twenty years later the privilege of mining coal was granted by William Penn. Anthracite was discovered in 1768.

Mine Surveying.—A beam compass with a scale and vernier attachment is described by C. Gregorie[†] for plotting surveys. By its aid measurements of one link and less can be plotted on plans of two chain and $\frac{1}{2500}$ scale.

L. C. Morganroth[‡] discusses the methods of preparing and keeping maps of collieries, both of the surface and of the underground workings.

A. Rost[§] has described the theodolites and other surveying instruments for use in mines which have been made by the firm of R. & A. Rost for the Paris Exhibition.

In order to obviate the errors in measuring lengths in mine surveys caused by variations in the tension of steel measuring-bands, M. Przyborski[‖] has devised an ingenious instrument, consisting chiefly of a spiral spring, which, placed at the end of the steel band, enables the tension to be regulated.

Two modifications in the adjustment of theodolites for use in mines are described and illustrated by W. Breithaupt.[¶]

D. R. Scott[**] deals exhaustively with the development of mine surveying instruments; O. Brathuhn[††] describes Langer's patent hanging compass; and F. H. Newell[‡‡] describes the hydrographic investigations of the United States Geological Survey in their relation to mining.

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[*] *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. pp. 203–205, with two illustrations.

[†] *Proceedings of the South Wales Institute of Engineers*, vol. xxi. pp. 527–530.

[‡] *Engineering and Mining Journal*, vol. lxx. pp. 367–368.

[§] *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii., *Beilage*, pp 45–48, with five illustrations.

[‖] *Ibid.*, p. 309.

[¶] *Ibid.*, vol. xlviii. p. 451, with two illustrations.

[**] *Transactions of the American Institute of Mining Engineers*, vol. xxviii. p. 679, vol. xxix. p. 931.

[††] *Zeitschrift für Vermessungswesen*, 1900, p. 186.

[‡‡] *Transactions of the American Institute of Mining Engineers*, February 1900.

The Economics of Coal-Mining.—Details are published* showing the wages earned and the work done at the Rossitz collieries, with an 11½-hour working day and with a 9-hour day. The coal mined per man and per year increased considerably, and the wages earned also showed an increase, but the increase in wage earned has been greater than in the work done. Another table shows the results achieved since the abandonment of shot-firing in the coal at the Segen-Gottes mine. On the whole the Company seems to have been none the worse off for this, though the results have been somewhat variable from year to year.

The merits and demerits of the double shift system in the Dortmund collieries are discussed.†

F. Danvers Power,‡ in a paper read before the Australasian Institute of Mining Engineers, gives suggestions for the ordering and distributing of mining stores and the keeping of the accounts.

Sanitation in Collieries.—The Conseil Supérieur d'Hygiène Publique at Brussels§ has issued a statement with reference to the parasitic disease so common amongst miners. The spread of the ancylostomiasis has aroused considerable attention in Belgium, and the matter has been investigated officially, and the information so gathered has led to this publication now referred to. It describes the origin of the disease and its mode of propagation. It is the larva of the worm that causes injury, and not the egg, as these latter pass away from the body. The parasite finds the best conditions for its existence in the absence of sunlight, the presence of moisture, and an elevation of temperature, which is less, however, than that of the human body. The subject is considered in much detail and numerous suggestions are made.

Faure and Philibert Baudot describe the miners' lavatories at the St. Etienne and Roche-la-Molière collieries.‖

Descriptions of Collieries. — Detailed descriptions have been published in the *Colliery Guardian* of a number of British collieries. The list includes the following colliery in the Fifeshire coalfield :—

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* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. p. 213.

† *Glückauf*, vol. xxxvi. pp. 407–413.

‡ *Iron and Coal Trades Review*, vol. lxi. pp. 307–308.

§ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. p. 288.

‖ *Comptes Rendus Mensuels de la Société de l'Industrie Minérale*, 1900, pp. 33-44.

Glencraig (vol. lxxix. p. 932). The collieries in the Lanarkshire coalfield described are:—Viewpark colliery (vol. lxxix. p. 979); Holytown colliery (p. 1025); Allanton colliery (p. 1078); Orbiston colliery (p. 1126); Dalzell and Broomside colliery (p. 1172); Rimmon, Calderhead, and Hartwood Hill collieries (p. 1219); Auchlochan colliery (vol. lxxx. p. 14); Shields colliery (p. 113). An illustrated description of the collieries of the Ebbw Vale Company has appeared.*

H. F. Bulman describes the following collieries:—Metropolitan in New South Wales (*Colliery Guardian*, vol. lxxix. p. 879); and the Aberdare Colliery, near Ipswich, in Queensland (p. 1123).

According to J. Jičinsky,† the Königin Luise Colliery, in Moravian-Ostrau, is worked by the State, and possesses seven winding shafts. Employment was given in 1899 to 7850 workpeople, and the output reached 2,956,995 tons of coal, valued at £1,095,000. One of the seams is 26 feet in thickness. The main working faces are lit by electric arc lamps. The method of working is described.

The Concordia Colliery has only one winding shaft, but the quantity wound through this one shaft is probably larger than through any other one shaft on the Continent of Europe, about a million tons having been raised in 1899. The pumps, fans, and other appliances are described.

J. Crankshaw ‡ gives some general notes on coal-mining in South Russia.

H. M. Cadell § describes a colliery in the Karharbari coalfield, and describes the miners and their work in some detail.

A short description of the collieries at Kebao, Tonking, has appeared.‖

IX.—*COAL-WASHING.*

Coal-Washing and Screening.—One of the course of lectures on mining recently published by Professor W. Galloway ¶ deal with the washing and screening of coal. A plan of the plant at the Nouvelle Marihaye collieries is given, and the process adopted there is described with the aid of illustrations of the machinery, and of some other forms of analogous machinery used elsewhere. Revolving tipplers, the screens of Briart, Coxe, Humboldt, Borgman-Emde, Karlick, and shaking screens, revolving screens, and various forms of picking bands are first considered, and then attention is directed to appliances used for washing nuts and fine coal.

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* *Iron and Coal Trades Review*, vol. lxi. pp. 169–172.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii., *Beilage*, pp. 80–81.

‡ *Transactions of the Manchester Geological Society*, vol. xxvi. pp. 410–419.

§ *Transactions of the Institution of Mining Engineers*, vol. xix. pp. 60–68.

‖ *Iron and Coal Trades Review*, vol. lxi. p. 217.

¶ *Proceedings of the South Wales Institute of Engineers*, vol. xxi., Appendix.

W. W. Beaumont * describes the vibromotor and its application to screening coal, giving illustrations of several forms in use. An arrangement of screen, driven by gearing and a flat-jointed rod, is made by the Hardy Patent Pick Company for screening coals, minerals, and other materials. A heavier form of vibromotor screen, as made by the same firm, for giving three different sizes of coal at the rate of about 350 tons per day, is used at the Low Moor and other collieries, and by Messrs. Cory & Sons, and a somewhat similar screen, giving five sizes of screen product, is shown in connection with a set of plant for crushing materials before screening, and for re-elevating the tailings to the screen after passing through a second crusher for further reduction in size. This arrangement secures a regular delivery of the material to the receiving end of the screen. Regular delivery by such means, or from hoppers or a vibrating shoot, should be insisted upon wherever possible, as this promotes the regular action of the screen and the better treatment of the materials acted upon. Coal screens of this kind are generally made in sizes up to 12 feet by 4 feet, with perforated screening plates, with holes from ¼ inch to 2½ inches and for giving five products: that is to say, for dust, slack, peas, nuts, and cobbles. Larger screens have been made. Those which are 12 feet by 4 feet will do from 200 to 300 tons per day with about 3½ to 4 horse-power, and according to the size of coal to be screened. Rope-driving is used in some cases, but belt-driving is preferred; belts of only about 3 inches wide being used for these large screens. The whole of the work done being utilised in the required result, very small power is used. The diameter of the gyratory circle described by these screens of the larger sizes for coal is generally not more than an inch, and the number of revolutions of the vibromotor spindle about 350 per minute. These figures, of course, vary with the screens of different sizes and for different purposes.

A plan of the new plant at Broomhill Colliery is given by J. E. O'Keefe † to show the banking and screening arrangements to deal with 1800 tons daily.

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* *Journal of the British Society of Mining Students*, vol. xx. pp. 105–115.

† *Ibid.* pp. 131–133.

An illustration has appeared* of two 400-ton Robinson washers erected in Alabama.

The coal-washing plant of the Dominion Coal Company in Nova Scotia, recently visited by the American Institute of Mining Engineers, consists of two Robinson-Ramsay coal-washers, with a combined capacity of 2000 tons of washed coal per day. The slack coal, deposited in bins with a storage capacity of 1200 tons, is raised to the top of the building and divided between the two washers. An average of 41 per cent. of the ash and 28 per cent. of the sulphur is removed by the washing. Coming frem the washers, the coal is carried over screens, and the water drained into tanks, whence it is pumped by four pulsometers of 1000 gallons capacity per minute, and used over and over again. After passing over the screens the coal falls into another elevator that takes it to the washed coal storage bin, holding 1800 tons.†

A description has appeared‡ of the surface arrangements and screening plant of the Gilly colliery near Charleroi in Belgium, where 152,800 tons were wound in the year in two shafts. Coxe's gyratory screens are in use.

Illustrations are given§ of the coal separating plant at the Königin Luise colliery. The coal from the pit is classified by the main plant into lumps, two grades of nuts, and smalls, the first three kinds being delivered on to picking bands and conveyors, whilst the smalls fall into a hopper, whence they are discharged through a shoot on to the endless belt which delivers them to the swinging screen on the way to the railway trucks. If it is desired to pass them through the secondary classifiers a shoot is closed by a shutter, and the coals fall on to the sloping screen, which is provided with a double bottom, the upper floor of which consists of perforated sheet metal of $\frac{3}{8}$-inch mesh, the lower floor being unperforated. The bulk of the dust coal drops through the meshes on to the lower floor, whence it falls through a shoot on to the conveyor. The screen is caused to swing by means of eccentrics. The smalls from the upper floor of the screen fall into a bin and are raised by an elevator to a Baum swinging screen, where they are classified into nuts I. and II., peas, and lump.

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* *American Manufacturer*, vol. lxvi. p. 277.

† *Canadian Mining Review*, vol. xix. p. 198.

‡ *Annales des Mines de Belgique*; *Colliery Guardian*, vol. lxxix. pp. 1186–1187.

§ *Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xlviii. pp. 109-111.

Purification of Waste Water from Coal-Washing.—R. A. Tatton[*] describes the processes adopted under different conditions for treating, previous to discharge into the neighbouring streams, the waste waters from three typical manufactories situated in the district of the Mersey and Irwell Joint Committee. Particulars of the cost of working are given in each case.

Slack-washing is a process employed at some collieries for separating small coal, which would otherwise be of little value, from the refuse with which it is mixed when raised from the pit. The water used in the process contains a large amount of solid matter in suspension, which can readily be intercepted in settling tanks. At some collieries a plant is used from which the solid refuse is removed during the process of washing, so that the water can be used over and over again, and none run to waste.

W. O. E. Meade-King[†] submits a statement of the results of an investigation carried out by him with a view to ascertain the action of various convenient precipitants upon the waste waters from thirteen manufactories. The waste water from coal-washing is, he shows, a very simple and, at the same time, inexpensive waste to deal with. It is quite possible, considering the nature of the works, that if tanks of sufficient capacity were provided, say, to hold a day's flow, no precipitant would be necessary; but if artificial precipitation is to be resorted to, then iron alum, with the addition of a small quantity of salt water, is all that is required, but it must be agitated or stirred after mixing. Two filtering mediums for the tank effluent would be sufficient, and these of the simplest character—coke and fine gravel—though, of course, the effluent could be improved if desired by further filtration.

Manufacture of Peat Fuel.—An important article has been published by Schöndeling[‡] on the manufacture of peat fuel. Illustrations are given of new forms of presses. Ordinary compressed peat contained 49·82 per cent. of carbon, 4·35 per cent. of hydrogen, 26·99 per cent. of oxygen and nitrogen, 15·50 per cent. of moisture, and 3·34 per cent. of ash. Peat may also be utilised by converting it into peat-charcoal. The same subject has been dealt with by the British Vice-Consul at Kieff, who reports that great attention is now being devoted to the question of peat as fuel, and that there is a good opportunity for the introduction of special machinery to utilise the immense tracts of peat land extending all over Russia. This question is being taken up by the Government. Commissions were appointed to consider the question, and have submitted a report on the subject embodying important suggestions as to the manner of bringing this simple industry before the peasantry of the country, and also suggesting that financial assistance should be granted by the Government for the purchase of the necessary machinery for the construction of narrow gauge railways, &c.

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[*] *Minutes of Proceedings of the Institution of Civil Engineers*, vol. cxl. pp. 2–19.

[†] *Ibid.*, pp. 20–71.

[‡] *Glückauf*, vol. xxxvi. pp. 793–797.

Handling Coal.—Illustrations are given * of the Temperley transporter erected at the Viscaya works, Bilbao, for discharging coal from vessels and piling it. The overhang on the water side is 43 feet, and on the land side 100 feet. Loads of 30 cwt. are handled with a hoisting speed of 300 feet, and a traversing speed of 600 to 800 feet per minute.

In a paper read before the *Verein Deutscher Eisenhüttenleute*, Aumund† considers the subject of transporting coal, and of charging and discharging it in transport. He deals with the Hunt appliance, which he describes in detail. Illustrations of this elevator are shown in connection with German works. Mention is made of a ship carrying 2300 tons of coal that was filled by two of these elevators in twenty-four hours. One of the illustrations shows this elevator as employed at Copenhagen in loading ships belonging to the Danish Coal Company. At Copenhagen alone there are employed thirteen of these elevators, and seventy-five automatic lines in connection with them. The subject is dealt with at considerable length.

Illustrations are given ‡ of a wire ropeway for handling coal at San Francisco.

Some illustrations of belt conveyors for handling coal have appeared.§

S. A. Everett || describes the surface arrangements for the delivery of coal from pit cage into railway waggons for a quantity of say 1500 tons per day, exclusive of coal-washing and coking.

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* *Iron and Coal Trades Review*, vol. lxi. pp. 727–730.

† *Stahl und Eisen*, vol. xx. pp. 825–836, with 11 illustrations.

‡ *Engineering and Mining Journal*, vol. lxx. p. 163.

§ *Iron and Coal Trades Review*, vol. lxi. pp. 780–782.

|| *Proceedings of the South Wales Institute of Engineers*, vol. xxi. pp. 386–451; *Canadian Mining Review*, vol. xix. pp. 154–160.

M. C. Minsier * describes the surface arrangements at a Belgian colliery.

Edward H. Coxe † discusses transportation on inclines, and describes the methods of getting coal down the mountain from mine to tipple in West Virginia.

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* *Annales des Mines de Belgique; Colliery Guardian*, vol. lxxix. p. 1186.

† *Mines and Minerals*, vol. xxi. pp. 10–11.

PRODUCTION OF PIG IRON.

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I.—*BLAST-FURNACE PRACTICE.*

A New English Blast-Furnace.—A. Sahlin* describes the reconstructed blast-furnace at Askam, belonging to the Millom and Askam Hæmatite Iron Company. The present plant consists of six furnaces 70 by 19½ feet at Millom, and four at Askam, 75 by 19½ feet. Of these, six at present are in blast, making 130 tons each daily of Bessemer pig iron.

The new furnace stack is 90 feet high, the steel shell being built of sufficient size to admit of a 20-foot bosh. The present lining will be built to a bosh diameter of 18 feet. The hearth measures 11 feet in diameter at the tuyere line, and is fitted with twelve 5-inch tuyeres placed 8 feet above the hearth level. Two slag notches are provided at opposite sides of the furnace. The tap-hole is closed by a mechanical stopper worked by compressed air. The hearth is bound with cast iron coil plates 3½ inches thick and 8 feet high. The phosphor bronze tuyere coolers are supported by a belt of 12 cast-steel collars strongly bolted together. The bosh is bound with five 9-inch by 1-inch steel hoops, and is cooled by 11 rows of cast-copper cooling plates. The shell is supported by six columns 26 feet high, resting on a solid iron base 18 inches high, and leaving the bosh and lower part of the shaft accessible. The stock line at top measures 14 feet in diameter, and is protected by iron plates built into the furnace wall. The

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* *Iron and Coal Trades Review*, vol. lx. pp. 1229–1230; *Iron Age*, July 12, 1900, pp. 14–15.

ordinary Parry bell is 9 feet in diameter. Bell and hopper are both built with separate seal rings cast in segments. The charging is done by a single skip hoist and an automatic rotating stock distributor of the Brown type. The skip has a capacity of 1 ton of coke or 2 tons of ore, and will handle 1300 tons of material per day. The top is also fitted with four self-registering sounding rods operating from the hoist engine-house, which is located in the stock-house near the foot of the hoist incline. This arrangement will do away with all labour on the top of the furnace. As the furnace is intended, if required, to work a large percentage of fine ore, eight 40-inch diameter explosion doors have been arranged around the shell under the steel top platform. The gas is drawn off by a 7-foot downcomer and enters tangentially near the bottom of the circular dust-catcher, which measures 15 feet in diameter by 50 feet in height. From the top of this dust-catcher, which is fitted with a large explosion door, a connection pipe runs to the horizontal 7 feet 6 inches diameter gas main, which supplies stoves and boilers. The stove power has been increased by two Cowper stoves, 21 feet in diameter, and 90 feet high. The remainder of the stove equipment is made up of two existing 26-feet by 75-feet Ford and Moncur stoves. The boiler power for the new furnace consists of 2000 horse-power Babcock and Willcox boilers arranged in four batteries of two boilers each. A plan and sectional elevation of the Askam works is appended.

Tamping Blast-Furnaces.—A sectional illustration* has appeared of Miller's magazine "mud-gun" for stopping the tap-holes of furnaces. In addition to the usual piston for pushing forward the clay, a second cylinder is attached to fill the charging tube from a reservoir placed above and at an angle with the lower tube. In the "mud-gun" illustrated the diameter of the upper cylinder is 12 inches, by 2 feet 7½ inches stroke. The magazine is also 12 inches in diameter by 2 feet 5½ inches stroke. The lower cylinder is 12 inches and the plunger is 8 inches in diameter. The diameter of the delivery nozzle is 6 inches, and the length over all from the nozzle to the end of the back cylinder is 7 feet 7 inches.

The Protection of Blast-Furnace Linings.—According to S. S. Hartranft,† replaceable bronze and copper plates are practically faultless for the protection of blast-furnace boshes and hearths, but very little attention is paid to the protection of the lining above the mantle. Some furnacemen use mantle-plates, while others do not; but to preserve the lines of the furnace, and thereby to prolong its life, something should be done. The Buffalo furnace, as put in blast in 1895, had three rows of double pipe cast-iron plates of the ordinary type above the mantle. The first row of these plates was placed 5 inches above the mantle, with the front edge of each plate 4½ inches from the inside line of the brickwork; the second row was 2½ feet above the first, with the front edge of each plate 9 inches from the inside line of the brickwork; and the third row was 2½ feet above the second, with the front edge of each plate 4½ inches from the inside line of the brickwork. After blowing-in, the furnace worked very well for the greater part of the first year, when it began hanging and slipping, which gradually became so pronounced as to interfere materially with the grade of the iron. About the end of the first year, the water circulation was lost on the inner pipes of the three rows of plates above described; after which there was no more hanging and slipping, while the grade of the iron improved and the output increased. In about a year and a half from the time the inner rows of pipes were lost, the outer rows were lost also; and there being no water protection left, the furnace soon enlarged at this point to such an unfavourable diameter and shape that it became necessary to blow out at the end of the third year.

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* *Iron and Coal Trades Review*, vol. lxi. pp. 833-834.

† *Transactions of the American Institute of Mining Engineers*, August 1900.

The ledge formed by the wearing away of the brickwork above the plates interferes with the regular descent, and when the pipes are lost the lining naturally wears away. This could be sufficiently retarded to ensure the retention of favourable lines, through the period of an average blast, by six rows of plates above the mantle, placed 2½ feet apart, with their front edges at least 9 inches from the inside line of the brickwork.

The author has also observed the result of fitting up a furnace with rows of solid cast-iron plates at the stock-line, and finds that these plates, with an inner edge 5 inches wide, placed in rows 1 foot apart, have worn well, and have protected the lining at this point. It would not be surprising to see, before long, furnace stocks plated from the mantle to a point above the stock-line with water-plates and solid plates. The only question difficult to decide will probably be the point in the ascent at which the water-plates should stop and the solid plates begin.

A New Form of Blast-Furnace Construction.—In a paper read before the *Verein deutscher Eisenhüttenleute*, F. Burgers * describes a modification in blast-furnace construction. This relates mainly to the shaft, which is of iron instead of the usual firebrick construction. The firebrick furnace lining corrodes as the furnace working proceeds, with the result that the internal shape of the furnace is subjected to great alterations. To avoid this there has been a tendency to more and more replace brickwork by cast-iron kept cool by water, and details are now given by the author of a furnace in which nearly all the shaft is of iron water-cooled, the brickwork of the whole furnace weighing only 130 tons, as compared with 1500 tons in the case of a similar sized furnace of ordinary form. Such a furnace is the No. 3 of the Vulcan Ironworks. At present, owing to inadequate blast supply, it is making but 85 tons of pig iron daily, containing 2½ to 3 per cent. of silicon. Compared with a neighbouring furnace of similar capacity and of ordinary construction, the iron furnace used about 5 per cent. more coke in most months, and the same quantity during two months. The author quotes various replies received from the United Kingdom and elsewhere, showing that as the furnace lining wears away the quantity of coke required per ton of pig iron made undergoes a considerable increase. In the course of a reply to a question by H. Wedding, the author said that the iron furnace can be hung up for a considerable time, and yet put into regular blast again at once, no scaffolding taking place. Some of the replies above referred to were to the effect that at Dowlais a new furnace requires from 19 to 20 cwt. of coke per ton of pig iron made, while old furnaces in which the lining has been worn need 22 to 23 cwt. From Middlesbrough answers were that new furnaces require from 20 to 22 cwt. of coke, while old ones used from 24 to 25 cwt. Similar replies from the United States were received.

Dust-Catchers.—At Les Hauts Fourneaux et Fonderies de Pont-à-Mousson † the Cavallier dust-catcher is employed, with a furnace producing 60 tons of foundry pig iron per twenty-four hours. The quantity of gas to be filtered is 350,000 cubic metres or 5800 cubic metres per ton of pig iron. This gas in passing through the Cavallier apparatus deposits 1388 lbs. of dust, from whence it is conveyed to two hot-air stoves and four boilers, depositing in the former 188 lbs.

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* *Stahl und Eisen*, vol. xx. pp. 675-680, with nine illustrations.

† *Revue Générale des Sciences; Colliery Guardian*, vol. lxxx. p. 935.

and in the latter 232 lbs. of dust. The appliance consists of a rectangular box, about 16 feet square, with a funnel-shaped bottom. A layer of iron scale, about 4 feet in thickness, is suspended in the centre, to act as a filtering material, and is arranged so that it can be shaken at intervals to allow the dust to fall through. The apparatus is also described by E. Demenge.*

Charging Blast-Furnaces Mechanically.—F. W. Lürmann† makes suggestions as to the mechanical charging of blast-furnaces. Referring to the inclined hoist of the Brown Hoisting and Conveying Machine Company of Cleveland, the author observes that by its use labour is saved; but these hoists are fixed, and there is one for every blast-furnace. If, therefore, anything should go wrong with one of these hoists, the blast-furnace it serves would have to go out of work while repairs were being made to the hoist. He suggests, therefore, that a hoist should be movable, like a travelling crane, and gives explanatory illustrations.

A. E. Maccoun ‡ states that an electrically driven hoist was started in 1898 at one of the Edgar-Thompson furnaces, and since then six more have been added. Tests show an average efficiency of 61 per cent., though the load raised varies from 1 to 5 tons. Their advantages as compared with steam-hoists are discussed.

Illustrations have appeared § of a hoist designed by E. G. Rust for blast-furnaces. A double track is provided on an inclined girder, one track being over the other, so that the skips running on them counterbalance each other but run to the same loading and discharging points.

An illustrated description has been published ‖ of the new Otto wire ropeway constructed for the Hoesch Ironworks at Dortmund. The line is 1160 feet long, the difference in level between the loading and discharging stations being 81½ feet, and the maximum gradient 1 in 8·4. The capacity of the line is 20 tons an hour. It is intended for the transport of coke to the blast-furnaces, and connects the coke-ovens with the blast-furnace plant.

Blowing-Engines.—Illustrations of a blowing-engine for an ironworks in Ohio have appeared.¶ It is of the steeple type, with air tubs over the steam-cylinders, which are cross compounded and condensing, 40 and 75 inches in diameter. The air cylinder is 78 inches in diameter, and the common stroke is 54 inches.

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* *Bulletin de la Société Industrielle de l'Est*, 1899–1900.

† *Stahl und Eisen*, vol. xx. pp. 561–564, with illustrations.

‡ *Iron Age*, June 28, 1900, p. 34.

§ *Ibid.*, September 6, 1900, pp. 10–11.

‖ *Stahl und Eisen*, vol. xx. pp. 981–982.

¶ *American Manufacturer*, vol. lxvi. p. 446; *Iron Age*, June 7, 1900, pp. 10–12.

Illustrations are given * of two sets of blowing-engines. In one set each engine consists of a pair of air cylinders 84 inches in diameter, and 60 inches stroke, driven by compound cylinders 48 inches and 84 inches diameter respectively, which take steam at 90 lbs. pressure and exhaust into a separate condensing plant. These engines are designed to run at 45 revolutions per minute, and to blow up to 20 lbs. blast pressure. The air cylinders of one engine are fitted with specially designed circular inlet and outlet valves, fitted in chambers attached to each end of the cylinders, and arranged for easy removal without disturbing any important part of the engines, the clearances being reduced to a minimum throughout without obstructing the free passage of air to and from the cylinders. The second set is fitted with Westgarth's patent pneumatic cushion valves, which are also described and illustrated. Another set of engines illustrated have the same size air cylinders, but the steam-cylinders are 37½ and 84 inches in diameter, taking steam at 150 lbs.

Pig-Breakers.—T. E. G. Marley † describes the steam-operated pig-breaker used by the Whitehaven Company at Cleator Moor, and E. James ‡ gives an account of the hydraulic machine at Dowlais. In the former machine, a pair of reversing engines with 7½ by 10 inch cylinders drives a second motion shaft geared to an eccentric which works the toggle levers operating the pig-breaking ram, and the sow-breaking ram is worked in a similar manner. Feeding and holding down arrangements are provided. The sow is generally cast with 31 pigs in the Cumberland district, and this comb is taken by an overhead traveller or crane to the feeding table. Three pigs are broken at a time, and then the corresponding length of sow is broken. The engine runs at 160 strokes and the machine about 8·8 strokes per minute, and breaks and loads 350 to 400 tons in nine hours. Eight men are employed in connection with the machine, and the cost amounts to 2·69 pence per ton. In the hydraulic machine, there are separate rams for the pigs and the sow, and another hydraulic ram operates the feed. Four pigs are broken at a time, and the valves are operated by hand, though at first their operation was automatic. Smaller hydraulic rams return the main rams. The cost is given at 1½d. per ton. The author also deals with the advantages of machine breakers, and the discussion turns to some extent on the sand question.

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* *Iron and Coal Trades Review*, vol. lxi. pp. 889–891.

† *Journal of the West of Scotland Iron and Steel Institute*, vol. vii. pp. 172–174, with plate.

‡ *Ibid.*, pp. 175–178, 183–189, with plate.

Pig Iron Casting Appliance.—K. Orth has designed a pig iron casting machine in which a number of moulds are placed longitudinally and in rows. Their movements are automatic, and can be regulated from one spot, both for filling, emptying, and subsequent transport. A description and illustrations of this appliance has appeared.*

An apparatus for facilitating the removal of pigs from the moulds of Uehling's pig iron casting machines has been in constant use at the Lucy Furnaces of the Carnegie Steel Company. A pin carried by a piston rod strikes the pig as the mould brings it in front of the cylinder to which the supply of steam is controlled by the chain of the casting machine.†

The Utilisation of Blast-Furnace Gas.—The utilisation of blast-furnace gas in gas-engines is considered by E. Demenge,‡ as regards the quality and quantity of the gases produced by blast-furnaces, their present and future use in motors, the principal engines that lend themselves to such utilisation, and the blowing-engines driven by these motors. The whole of the paper is, in fact, a summary of what has been done in this direction, and it is supplemented by numerous illustrations of the engines and plant now at work, and an account of the Cavallier dust-catcher, previously referred to in this volume. The author adds a table showing the works owning gas-engines driven by blast-furnace gas, and giving the names of the builders of the engines, the situation of the works, the system, number, and horse-power of the engines, the number of their cylinders, and the uses to which they are applied. These uses include the generation of electricity, transmission of power, the driving of blowing-engines and air compressors, lighting, pumping, &c. The number and horse-power as distributed in various countries is as follows:—

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* *Stahl und Eisen*, vol. xx. pp. 1033–1037, with 12 illustrations.

† *Iron and Coal Trades Review*, vol. lxi. p. 316.

‡ *Bulletin de la Société de l'Est de la France*, 1899–1900; *Colliery Guardian*, vol. lxxix. pp. 996–998.

	Number of Engines.	Horse-Power.
France	10	4,710
Belgium	8	3,700
Luxemburg	12	6,700
Germany	43	22,950
England	6	2,060
Totals	79	40,120

The tests recently made with the Delamare-Deboutteville and Cockerill 600 horse-power gas-engine, consuming blast-furnace gas, are fully described in a report drawn up by Professor Hubert of the Liége University.

Brake tests were first made, and then the engine was coupled to the blowing cylinder and further tests taken, and of these full details are given. The results obtained in five brake tests furnished the following averages, calculated on the total duration of the tests:—Number of admissions per minute, 41·90; indicated horse-power, 786·16; mean speed, 94·37 revolutions per minute; effective output measured at the brake, 575 horse-power; mechanical efficiency of the motor, 73·14 per cent.; volume of gas (at 0° C. and 760 mm.) consumed per minute, 1180 cubic feet; consumption of gas per hour, 90·2 cubic feet per indicated horse-power, or 123·5 cubic feet per brake horse-power; water consumed in the cylinder 12½ gallons, in the piston, 2·8 gallons; mean temperature of the water in the cylinder on entry 7·86° C., on exit 33·17° C.; mean temperature of the gas on entering the engine, 9° C.; at the waste pipe, 508·5° C. In a subsequent test the mean number of revolutions per minute was 92·48, and the number of admissions 46·28, the calculated mechanical efficiency being 80·40 per cent. under these conditions; but for a portion of the time the speed averaged 93·20, the admissions 46·22, and the efficiency 81·12 per cent.

Following the brake tests, a series of readings was taken with the motor in actual work driving the blower at a mean speed of 83·92 revolutions per minute, the blower therefore making double that number of strokes and developing a mean air pressure equivalent to 395 mm. mercury gauge. The proportion of admissions was 86·5 per cent., and the mean mechanical efficiency 75·33 per cent. A second set of tests was then made with the admission of gas regulated so as to avoid misses, the mean speed being increased to 93 revolutions, and the mechanical efficiency to nearly 82 per cent., the blast pressure being at the same time raised to 448 mm. The experiments are summed up in the statement that 28 per cent. of the heat was converted into work in the cylinder, 20 per cent. was lost in the waste gas and otherwise, while 52 per cent. was carried away in the cooling water.

The increasing use of large gas-engines for power purposes is discussed by M. Münzel.* A number of such engines are described, and the progress of the gas-engine considered generally, together with the establishment of central power stations. Some modern plants are dealt with in some detail.

The first tests of the 600 horse-power gas-engine constructed at the Seraing works to utilise the blast-furnace gases were made there on March 20 and 21. A description of this gas-engine is published.† The gas is taken from the main lead and is sent direct to the engine without any separation of the dust it may contain. The results were very satisfactory.

Details are published ‡ as to the very satisfactory results obtained in connection with the 600 horse-power engine driven by blast-furnace gas at Seraing. The engine was driven by gas taken direct from the boiler leads without further purification.

E. Meyer § also deals at considerable length with the experiments made with the 600 horse-power engine driven by blast-furnace gas at the Seraing works, and working a blowing-engine.

The large engines at the Donnersmarckhütte and the Friedenshütte, which have been erected for the utilisation of blast-furnace gases, are described. According to Müller,‖ there had been at work continuously for five months at the Donnersmarck works a 100 effective horse-power gas-engine, having a 19·7 inch cylinder, 33·5 inches stroke, and making 130 revolutions in the minute. It is used for driving a dynamo coupled direct to it. There has only been one stoppage for repairs in the whole five months, and that was merely to replace a spring forming part of the igniting arrangement, and consequently had nothing to do with the utilisation of the gas as the source of power. The blast-furnace gas used for this purpose is of about 1000 calories value, and contains per cent. by volume—

Carbon Monoxide.	Hydrogen.	Carbon Dioxide.
31	3·4	7·8

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* *Stahl und Eisen*, vol. xx. pp. 315–320, 382–392, with 14 illustrations.

† *Ibid.*, p. 401.

‡ *Ibid.*, pp. 419–420, with two illustrations.

§ *Ibid.*, pp. 721–729, with three illustrations.

‖ Paper read before the *Eisenhütte Oberschlesien*, January 21, 1900; *Stahl und Eisen*, vol. xx. pp. 413–416, with three illustrations.

The gas is passed through a scrubber and a sawdust purifier to free it from entangled dust. The scrubber was at first filled with coke in large pieces. The gas entered from below and escaped at the top, and water was sprayed in under the cover of the scrubber. It was found that the dust particles separated from the gas in the scrubber soon began to hinder considerably the passage of the gas through the coke, and that the scrubber had quickly to be cleaned. As this work took up time and cost money, the coke was done away with, and only the water-spray used. The results were equally satisfactory. The deposited dust escaped continuously from the scrubber in the form of thin mud through a syphon tube. The quantity is inconsiderable, the dust collected only weighing about 3·3 lbs. per 100 horse-power per day. The gas then passes through the sawdust purifier. In this there are two layers of sawdust, each about 4 to 6 inches thick, and through these the gas rises. Only a very small quantity of dust is here deposited. The sawdust has to be renewed every four weeks, as by that time it is heavily charged with dust. The gas leads also act as dust-collectors, and have to be cleaned every Sunday. This point needs consideration at those works where it is not possible to clean up the lead on Sunday. From about 91 to 99 cubic feet of gas is used on the average per effective horse-power and per hour. The oil used per day amounts to about 6 lbs., 2·2 lbs. being "cylinder" oil and the remainder "machine" oil. The water used amounts to from 2825 to 3530 cubic feet per day. The piston and cylinder were found to be in quite as good condition after three months' work as they would have been in the case of a good steam-engine, and no wear could be detected. The results have been so satisfactory that a 600 horse-power engine has been since ordered by the same works from Messrs. Körting, the makers of the smaller engine to which the above refers. The author shows that the use of the blast-furnace gas in this way effects an enormous annual saving.

F. Werndl* describes the gas-engine plant at the Friedenshütte. Most of the dust which escapes from the blast-furnaces with the gas, he points out, is collected in the dry dust-collectors attached to the furnaces. If no other dust-separators are used, the very fine dust passes into the gas-engine. Most of it is subsequently blown out of the cylinder. Indeed so much is this the case, that after a month's run of one of the blast-furnace gas-engines at the Friedenshütte, only about a pound of dust could be scraped out of the explosion chamber and from the piston bottom. When more than one blast-furnace is at work at the same time, the average composition of the escaping gases does not vary very greatly as a whole, but a regulator attached to the gas-engine permitting more or less gas to enter allows even for considerable variations in this direction. The moisture in the gas reduces its calorific power, but this has been found at the Friedenshütte to be quite high enough, given adequate compression, to yield the necessary power at the moment of explosion. The gas from the Friedenshütte blast-furnaces has to pass for a distance of about 550 yards before it reaches the gas-engine. It passes through a series of dry scrubbers. Some were at first filled with porous coke, but this soon clogged, and now these coke scrubbers are left empty. They finally pass through sawdust purifiers to a gasometer, whence they subsequently pass to the engines. The natural gas pressure, as it comes from the blast-furnace, is high enough to force the gas to the engines, where it still amounts to from 0·8 inch to 2·36 inches of water. The works possess two 200 horse-power Otto gas engines, and two of 300 horse-power each. The former are used for electric lighting, and the two larger engines for the electric transmission of power. These engines are described. The gas as it leaves the blast-furnace has a pressure of from 3·5 to 5·9 inches of water and a temperature of about 330° C. At the engines the pressure has fallen to that already mentioned, and the temperature to only 8° to 13° C. After passing the dry purifiers at the blast-furnace the gas contains about 5 grammes of dust per cubic metre (35·32 cubic feet). Just before the sawdust purifiers the quantity is only 0·6 to 1·6 gramme per cubic metre, and only a few thousandths of a gramme after passing through the sawdust. The moisture in the cubic metre of gas was found to be 13·5 grammes before the sawdust was passed through, and but 5·5 grammes afterwards. The gas as it enters the engines contains per cent.:—

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* Paper read before the *Eisenhütte Oberschlesien*, January 21, 1900; *Stahl und Eisen*, vol. xx. pp. 416–419, with three illustrations.

Carbon Monoxide.	Hydrogen.	Carbon Dioxide.
28 to 30	3 to 3·5	6 to 7

The 200 horse-power engines, when working at only a 90 horse-power rate, use 233 cubic feet of blast-furnace gas, or 183·6 cubic feet of producer gas per horse-power and per hour. When, however, yielding 177 horse-power they only wanted 134 cubic feet of gas per horse-power hour, whence it will be seen that when doing their maximum work they require scarcely 124 cubic feet of blast-furnace gas per horse-power hour. The water required in the case of a 200 horse-power engine was about 265 cubic feet in twenty-four hours, and half as much again in the case of the larger form of engine. The author anticipates that the use of engines driven by blast-furnace gases will soon be widespread.

Since the commencement of June 1900, a 600 horse-power engine worked by blast-furnace gas has been at work at the Gutehoffnungshütte, Oberhausen. It has given full satisfaction. It works a dynamo which produces a 3000-volt current, by the aid of which a pumping plant is driven at a distance of about five miles from the works. A second blast-furnace gas-engine has recently been started. It is of 300 horse-power capacity, and has also proved very satisfactory. Indeed so much has this been the case, that a third engine of this type and of 300 horse-power is being erected, and from the Deutz Gas Motor Factory, where these engines were made. The same works has ordered four other gas motors, each of 500 horse-power, and one of 1000 horse-power.*

The utilisation of blast-furnace gases in gas-engines, and especially as connected with the production of calcium carbide, is discussed by Neumann.† The author deals with the question of cost as follows:— The costs of the horse-power derived from blast-furnace gas are composed of the general annual costs and the costs of the fuel. In the case of a thousand horse-power plant working for twenty-four hours on 300 days in the year there are 7200 working hours per year. The complete cost of a gas-engine plant, including the pipe lines and other charges, would be about £10,000. Allowing 4 per cent. for interest and writing off 10 per cent., this would amount to £1400. The workmen necessary are one engineer and one assistant with a joint annual wage of £200; consumption of lubricating oil may be placed at double that of an ordinary steam-engine, or rather over 1s. 6d. per hour, say £620 per year. The total working costs would consequently be about £2200 per annum. The calculation of the cost of fuel is more complicated, but the author deals with this, and estimates the total cost of one horse-power to be £3, 17s. inclusive. The same subject is also dealt with by F. Liebetanz.‡

A. Wagener§ discusses the use of gas for power-raising purposes. The application of waste blast-furnace gas for this purpose is discussed at some length, and gas-engines generally are passed in review. The greatest danger in the safe working of a gas-engine lies in the attainment of too high pressure and too high temperature. The use of "power gas" prepared on the Oechelhäuser system by the *Deutsche Kraftgas-Gesellschaft* is specially referred to. The use of power gas, as distinguished from blast-furnace gas, is generally dealt with, as also is the progress that has been made in the use of gas-engines, which, though long looked upon with favour theoretically, have only of late years begun generally to be adopted in practice on any large scale.

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* *Stahl und Eisen*, vol. xx. p. 714.

† *Ibid.*, vol. xx. pp. 1019–1020.

‡ *Ibid.*, p. 1020.

§ *Ibid.*, pp. 1080–1089, with five illustrations in text and one plate.

M. Münzel* compares the 600 horse-power Cockerill engine to be worked with blast-furnace gas with a 600 horse-power and a 1200 horse-power engine made by the Deutz Company. The latter have four cylinders. He shows that the latter possess advantages over the former.

A. D. Adams† points out that about half the energy of the gas is lost in the water used for cooling the cylinders of gas-engines, and in addition there is the waste heat in the exhaust. This heat might be utilised for hot water heating systems, or in other ways.

According to Osann,‡ there is produced in Germany and Luxemburg 920 tons of pig iron per hour. The gas resulting would be equivalent to the production of 377,200 horse-power per hour if gas-engines were utilised. The saving in coal would amount to about £16,500,000 per annum. The question of the utilisation of blast-furnace gases in gas-engines is dealt with generally by the author.

E. Meyer§ describes various gas-engines for using blast-furnace gas, including a 600 horse-power two-cycle Oechelhäuser engine. The stroke is 31·5 inches, and the diameter of the cylinders is 18·9 inches. The speed is 135 revolutions per minute, and the gas consumption is given as 124 cubic feet per horse-power hour.

The use of blast-furnace gas for motive power is described by O. E. Westin,‖ who gives a historical summary of the development of the gas-engines used.

E. Theisen¶ describes his method for the purification of blast-furnace and other works gases. It consists in the use of a centrifugal gas-washer. One such apparatus has recently been erected at the Hörde works. It is cylindrical in form, about 5 feet in width by 15 feet in length. It is placed rather over 16 feet from the main gas lead, which serves three blast-furnaces, and at a distance of 361 feet from the nearest of these. There is a pressure of about an inch to an inch and a half of water in the gas main, and from it the gas is exhausted by the washer, and driven forward with a pressure of from 4·7 to 5·9 inches of water column into a collecting main for the purified gas, from which the gas motors are served. Before its entry into the washer the gas contains per cubic metre 3·3425 grammes of dust, whereas after washing, the average of fourteen assays showed only 0·010 gramme. The wash water amounts to above a litre per cubic metre of gas washed, some hundred cubic metres being passed through the washer per minute. The moisture in the gas before entering the washer amounted to 36·21 grammes per cubic metre, whereas subsequently it was only 3·013 grammes.

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* *Stahl und Eisen*, vol. xx. p. 1095.

† *Engineering Magazine*, vol. xix. pp. 523–528.

‡ *Zeitschrift des Vereines deutscher Ingenieure*, vol. xliv. pp. 886–887.

§ *Ibid.*, p. 1056, with plate.

‖ *Jernkontorets Annaler*, 1900, pp. 369–461.

¶ *Stahl und Eisen*, vol. xx. pp. 1037-1041, with one illustration.

The Early Anthracite Iron Industry.—S. Thomas * of Catasauqua, Pennsylvania, gives an interesting series of his own and his father's reminiscences, and a number of quotations concerning the early anthracite iron industry. Commencing with a short account of the works at Yniscedwin in Wales, the author then describes the start of the anthracite furnaces of the Lehigh works under the care of David Thomas, and gives a number of sections of the blast-furnaces built at Catasaugua, beginning with the first erected in 1839–40. Illustrations are also given of the old beam blowing-engines driven by waterwheels. Amongst the experiments tried at these works was one in 1847 which consisted in passing a strong electric current through the molten iron in the furnace, but naturally it produced no improvement in the iron used for puddling.

Canadian Blast-Furnaces.—W. Fawcett † gives a general account of the ore, coal, and coke resources of the Dominion Iron and Steel Company, which is building four blast-furnaces at Sydney in Cape Breton. The furnaces will be 85 feet by 19 feet, and a basic open-hearth plant is to be added.

New American Blast-Furnace.—The Marting Iron and Steel Company are building a new blast-furnace plant at Columbus, Ohio, of which particulars are given,* together with a plan and other illustrations. There are two furnaces 17 by 75 feet, with six hot-blast stoves 18 by 75 feet, and room for two more stoves. Five blowing-engines with air cylinders 54 by 84 inches are provided, and six 350 horse-power vertical tubular boilers. Each furnace has a casting-house 60 by 175 feet. The Kennedy filling arrangements are fitted to these furnaces, and these are also described.†

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* *Transactions of the American Institute of Mining Engineers*, vol. xxix. pp. 901-928.
† *Iron Trade Review*, May 17, 1900, pp. 12–14.

Some illustrations have appeared ‡ of the blast-furnace and steel plant and collieries of the Ashland Coal and Iron Co. at Huntington, West Virginia. There are three blast-furnaces at work served by 12 stoves.

New Belgian Blast-Furnace.—At Couillet, in Belgium, a large new blast-furnace has been completed. It is the first blast-furnace of the American type erected on the Continent.§

Blast-Furnace at Malaga.—Details are given || of the new blast-furnace just started at Malaga. The furnace is 80 feet in height, and its maximum diameter is 19 feet. There are three Cowper stoves in use and one in reserve. There are three boilers heated by the furnace waste gases. A 25-ton open-hearth furnace has also been built. The ore smelted in the blast-furnace is hæmatite from Casariche, with coke from Belmez. The present output is 80 tons a day.

II.—*CHEMICAL COMPOSITION OF PIG IRON.*

The Effect of Remelting Pig Iron.—T. D. West ¶ gives some analyses to show the effect of remelting iron and scrap steel. The following table shows the effect of five remelts on charcoal pig iron:—

	Charcoal Pig Iron.	First Remelt.	Second Remelt.	Third Remelt.	Fourth Remelt.	Fifth Remelt.
Total carbon . . .	3·94	4·10	4·30	4·47	4·68	4·76
Graphitic carbon . .	3·06	2·90	2·42	2·90	2·67	3·16
Combined carbon . .	0·88	1·20	1·90	1·57	2·01	1·60
Silicon	0·82	0·75	0·63	0·66	0·57	0·59
Sulphur	0·02	0·03	0·04	0·04	0·045	0·048
Manganese	0·78	0·66	0·53	0·31	...	0·25
Phosphorus	0·232	0·248	0·274	0·237	0·254	0·271
Specific gravity . . .	7·01	7·30	7·35	7·40	7·47	7·46

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* *Iron Age*, May 3, 1900, p. 17; *Iron and Coal Trades Review*, vol. lx. pp. 947–948.

† *Iron and Coal Trades Review*, vol. lx. p. 456.

‡ *Ibid.*, pp. 1033–1034.

§ *Mining Journal*, vol. lxx. p. 1061.

|| *Revista Minera*, vol. li. p. 481.

¶ *American Machinist*, vol. xxiii. pp. 428–429.

Occurrence of Vanadium in Pig Iron.—L. Blum * observes that the element vanadium found by Sefström in 1830 in Eckersholm bar iron is still looked upon as one of the rare elements, although its occurrence is somewhat widespread. As vanadic acid it is frequently present in small quantities in iron ore, and this is to a large extent reduced when the ores are smelted in the blast-furnace, passing as vanadium into the pig iron. When hot-blown pig iron is tapped, a thin scum of slag always forms on the surface, and this flies off when the iron solidifies. No one, however, mentions the presence of vanadium in this. The author, therefore, was much surprised to find a large percentage of vanadic acid in such a thin slag deposit formed on the surface of basic pig iron free from manganese. This iron had been made exclusively from Luxemburg minette. Analysis of the slag showed:—

	Per Cent.
Silica	8·40
Ferrous oxide	74·86
Manganous oxide	3·26
Sulphur	0·44
Phosphoric acid	9·94
Vanadic acid	2·56
Total	99·46

The pig iron itself only contained 0·015 per cent. of vanadium, and the great enrichment in the slag film consequently shows the ready oxidisability of vanadium contained in the iron. It is true that in such a metal all the conditions exist which would facilitate the enrichment of the vanadium in the slag coating, the silicon contents of this pig iron rarely exceeding 0·6 per cent., while the percentage of manganese is not more than 0·4 or 0·5, and its sulphur contents is always less than 0·15 per cent. Those substances which are readily oxidised by the air when the pig iron is tapped are therefore present only in small quantities, whence the quantity of slag formed is much smaller than would be the case, say, with a grey pig iron high in silicon, or basic metal containing several per cent. of manganese. It is evident, however, that this slag film would form an excellent material for the manufacture of vanadium. The percentage of vanadium in the minettes has not been determined, but estimating from the above percentage in the pig iron it cannot exceed about 0·01.

Phosphoric Chalk in the Blast-Furnace.—It is stated that arrangements are being made to introduce phosphoric chalk in place of puddlers' tap in the blast-furnace. This material has been in use for some time in Belgium, in the North of France, and in Germany, where the supplies of puddlers' tap are now becoming exhausted In view of the impending exhaustion and high price of best puddlers' tap in Great Britain, basic pig iron makers have recently turned their attention to these supplies of phosphoric chalk from the Somme district, and several lots have already been bought for delivery in the United Kingdom.

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* *Stahl und Eisen*, vol. xx. pp. 393–394.

In Belgium blast-furnaces phosphoric chalk works well, and a comparison of furnace burdens, without and with phosphoric chalk, is given to show the advantage of using the latter in preference to puddlers' tap. These furnaces now use minette (Luxemburg) ore, mixed with Gellivare (Swedish) ore and phosphoric chalk, and no puddlers' tap or mill scale. On the furnace charge for pig iron containing about 1·94 per cent. of phosphorus, the use of chalk effected a saving of about sevenpence per ton. The tables appended show the analyses and weights of the materials used and produced.*

III.—*BLAST-FURNACE SLAG.*

Utilisation of Blast-Furnace Slag.—A plant for making slag cement and paving flags has been put into operation in Barrow-in-Furness. Two grinding machines of American make are fed from a large hopper capable of holding two trucks of slag, and each turns out five tons hourly, absorbing 50 horse-power. The ground material is bagged without being touched by hand. The slag dryer is a revolving cylinder 40 feet long.†

A. Birk ‡ describes the Königshof slag cement. The granulated blast-furnace slag from the Carl-Emil works at Königshof contains:—

SiO_2.	CaO.	Al_2O_3.	MgO.	FeO.	MnO.
26·29	49·16	18·71	2·45	1·80	0·24

The three most important constituents vary, as a rule, as follows:—

	Per Cent.
Silica	24 to 27
Lime	49 ,, 54
Alumina	15 ,, 19

This slag may be compared as regards composition with the slag from the Choindez ironworks, which has found general application in practice as in the form of slag cement. This slag contains:—

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[*] Pamphlet communicated by Messrs. C. E. Muller & Co., of Middlesbrough.

[†] *Iron and Coal Trades Review*, vol. lxi. p. 773.

[‡] *Technische Blätter*, 1899, Nos. 2 and 3; *Stahl und Eisen*, vol. xx. pp. 886-891.

	Per Cent.
Silica	26·22 to 27·51
Lime	45·11 „ 48·52
Alumina	22·40 „ 23·16
Ferrous oxide	0·44 „ 1·36
Magnesia	traces „ 1·19

In the Königshof slag the ratios of $CaO : SiO_2 : Al_2O_3$ are as 1 : 0·54 : 0·38, and in Choindez slag as 1 : 0·55 : 0·46. It would thus seem that the Königshof slag is especially well suited for cement manufacture.

The slag sand after selection is dried and then ground. This grinding is carried to such an extent that no residue is left on a sieve with 900 meshes to the square centimetre (1 square centimetre equals 0·155 square inch), and not more than 15 per cent. on a sieve with 5000 meshes to the square centimetre. The degree of fineness is of very great importance, as Tetmajer has shown; the finer the sand up to the above limit the better being the cement. Slag of the above fineness gives a perfectly satisfactory cement, and it is therefore needless to carry the grinding any further. The lime used for the slag cement manufactured at the Königshof works is from Silurian limestone from the Koneprus quarries.) It is burnt in two continuous shaft kilns. The following is an analysis:—

	Per Cent.
Lime	81·546
Magnesia	1·751
Soda	0·211
Manganous oxide	traces
Ferric oxide	0·883
Alumina	2·620
Silica	12·421
Carbon dioxide	0·194
Moisture	0·425

The lime having been hydrated and kept until it has fallen into the finest possible powder, all coarser particles are then separated. The lime and the slag are then ground together in the proportions considered requisite. This not only mixes the materials thoroughly, but brings them to the same size. The following are analyses of slag cements:—

	Königshof.	Perlmoos.
	Per Cent.	Per Cent.
Silica	20·81	23·36
Sulphuric acid	0·91	0·64
Alumina	10·50	9·20
Ferric oxide	1·90	5·12
Manganous oxide	0·40	...
Lime	55·90	54·18
Magnesia	1·41	1·32
Sulphur as sulphide	0·58	...
Potash	...	0·58
Soda	...	0·70
Carbon dioxide	...	1·90
Loss on ignition	3·50	...

Another analysis given by Tetmajer is also shown. The author next considers the properties of the Königshof slag cement in detail. Its specific gravity lies as a rule between 2·80 and 2·90, and it is about 5 to 6 per cent. lighter than Portland cement. Being so light, it can be very readily brought into thorough admixture with sand and water. It sets somewhat slowly. A good cement must not increase its volume during the setting. An increase of volume is especially disadvantageous, and the Königshof cement gives excellent results in this direction, showing no increase of volume whatever. The author next gives in detail the results of a large series of tests of this cement, and shows that it is generally very satisfactory.

A. D. Elbers * discusses the use, on land, of slag from blast-furnaces, and shows that when it is of a basic nature it may be employed for liming purposes.

G. Kroupa † describes and illustrates some American methods for the removal of slag, but these, though of general interest, relate directly to lead and copper smelting. One such consists in the granulation of the slag and its subsequent removal by a current of water.

IV.—*FOUNDRY PRACTICE.*

Foundry Appliances.—R. Moldenke ‡ shows what an extensive field there is for the conveyor in foundries. For sand, coal, coke, and for the castings shaken out of the moulds it is especially suitable. It is also used to convey moulds to the casting point. For handling pig iron and leading it to the cupola or reverberatory furnace, the conveyor is not well adapted except in special instances.

J. A. Murphy § discusses some of the points which tend towards good work in foundry management, especial reference being made to good lighting, appliances, material and labour.

Illustrations have been published ‖ to show the main foundry, cupolas, and charging floor, and a moulding pit at Cramp & Sons' foundry, Philadelphia. The floor area is 37,920 square feet, with 9000 feet of gallery space. Two 50-ton electric travelling cranes command the main building. The cupolas are three in number, 68, 58, and 32 inches in diameter respectively.

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* *American Manufacturer*, vol. lxvii. pp. 276–277.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. pp. 31–33, with numerous illustrations.

‡ *Iron Trade Review*, June 14, 1900, p. 26.

§ *Journal of the American Foundrymen's Association*, vol. ix., Part I., pp. 17–24.

‖ *Iron Trade Review*, June 14, 1900, pp. 8–9.

A plan is also given* of a new foundry at East Birmingham, Alabama, having one 72 and one 54 inch cupola.

E. H. Mumford† considers the use of moulding machines, chiefly in view of the labour problem in the United States.

E. H. Pierce‡ discusses the dimensions of wooden foundry flasks, which are often made of too slight material. Dimensions are given of the sides and bars which should be used. P. R. Ramp§ advocates the use of iron as preferable for the manufacture of flasks.

J. Horner‖ gives a number of illustrations of different types of cranes adapted to foundry use, including swinging-jib cranes, overhead travellers, and suspended hoists running on overhead trucks. Compressed air, hydraulic, and electric power are applied in the instances shown.

A. D. Williams¶ describes the construction and use of electric foundry cranes of various types. Some attention is paid to the question of break-downs, and it is pointed out that overhead travellers cannot entirely replace the use of hand-worked jib cranes.

E. B. Gilmour** discusses the influence of sharp corners, angles, and bends on castings, and shows that they produce lines of weakness due to the irregularity of crystallisation, which is accounted for by the unequal escape of heat. Examples are given.

Cupola Practice.—L. C. Jewett†† discusses the ratio of fuel consumed to the iron melted in the cupola, and shows that a ratio of 10 to 1 may make a slight saving in the fuel, but there is loss in obtaining cold iron, which chills in the ladles, and does not fill the moulds properly.

Pipe Founding.—E. Kebler‡‡ gives some notes on the American practice of pipe founding. The pit is circular, with a rectangular offset, at the end of which is a drying oven. The centre of the pit is built up to the level and supports two cranes. Iron flasks, hinged vertically, are used, and are rammed in a vertical position by hand or by machinery. Small pipes are usually moulded socket up, but pipes over 10 inches in diameter are moulded with the socket at the bottom. The moulds are dried from the inside by air passing through them as they are placed vertically in the oven. The cores are made by wrapping hayband on a steel core bar, and then coating it with clay which is subsequently blacked. Collapsable core bars and other substitutes for hayband have not answered. Cupola-melted iron is used for casting. The pipes are cooled, stripped, the core knocked out, and the fins, &c., cleaned off, after which the pipes are coated and then tested. Thin soil pipes are cast on the side in greensand with greensand cores.

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* *Iron Trade Review*, September 6, pp. 12–13.

† *Journal of the American Foundrymen's Association*, vol. ix. pp. 69–73.

‡ *Ibid.*, vol. ix. Part I. pp. 24–27.

§ *Ibid.*, vol. ix. p. 15.

‖ *Cassier's Magazine*, vol. xviii. pp. 214–242.

¶ *Journal of the American Foundrymen's Association*, vol. ix. pp. 75–82.

** *Ibid.*, pp. 31–35.

†† *Ibid.*, pp. 28–31.

‡‡ Paper read before the Foundrymen's Association.

C. A. Meissner * gives a specification for pipes used by the British Admiralty and others, and generally deals with various points arising in their manufacture and use.

Cast Iron for Hydraulic Castings.—R. P. Cunningham † discusses the mixing and melting of iron for hydraulic castings, and advocates mixtures containing 1·20 to 1·50 silicon, 0·60 to 0·80 phosphorus, 0·40 to 0·60 manganese, and sulphur as low as possible, in order to obtain close-grained castings, which will prevent water under pressure from coming through. Care in the use of scrap and the use of plenty of fuel is requisite.

Chilled Rolls.—The manufacture and care of chilled rolls is dealt with in a recent article.‡ Uniformity of composition and careful selection of material is very necessary, and great care is requisite to get a chill of uniform depth. The metal is generally melted in air furnaces, and cast from below in vertical chill moulds, with sand at the necks and wobblers. Until recently, nearly all the tinplate rolls in the United States were 24 inches in diameter, and generally 36 inches or 38 inches long. The rolls used in the first tinplate works in the United States were smaller than this, and those used in Wales were still smaller, the Welsh rolls being from 16 inches to 18 inches in diameter, and correspondingly short. Now a great many tinplate rolls in the United States are 20 inches in diameter, and from 40 inches to 44 inches in length. The life of the roll is then dealt with, especially in so far as it is affected by the strains set up by too sudden heating or cooling. One case is quoted in which a draught of air playing on to a stand of rolls caused constant breakages.

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* *Journal of the Mining Society of Nova Scotia*, vol. v. pp. 47–54.

† *Journal of the American Foundrymen's Association*, vol. ix. pp. 36–40.

‡ *Iron and Coal Trades Review*, vol. lxi. pp. 416–418.

Carborundum in the Cupola.—According to F. J. Tone* a somewhat extensive use is now made of carborundum, or carbide of silicon, in the foundry as an addition for both steel and cast-iron castings. An average analysis of the material shows:—

Si.	C.	Fe.	Al.
62	35	1·5	1·5

In the manufacture of steel it is placed in the ladle, and the molten metal is run on to it; but with cast-iron the temperature, and accordingly the rate of solution, is too low, so it is charged in lump or brick form into the cupola on the top of each coke charge. With its aid burnt iron or rusty scrap is successfully melted and cast, the silicon combining with the oxygen, and acting to liberate the graphite in the iron.

Malleable Castings.—The full text has been published of a paper by C. James,† in which he discusses the annealing of white cast iron produced by melting mixtures of white and grey coke iron with an average composition of:—

C.	Si.	Mn.	S.	P.
3·40–3·80	0·90–1·20	0·35–0·20	0·05–0·04	0·04–0·03

The higher silicon is used when hot and fluid metal is required. Generally an air furnace is used with a charge of three to five tons pre-heated before charging. The melting takes 3¼ to 3¾ hours. Cast tests then show a grey fracture, and fining is continued for 30 to 45 minutes, until the test is free from grey iron. The castings are annealed in charges of two to three tons, either in the open furnace or in boxes. No difference in the results except as regards scale is observed. The time required varies from 3½ to 10 hours from the moment when the castings attain the full temperature required for the carbon change, which is about 1850° F., but this depends partly on the composition. The following analysis shows the change in ordinary work:—

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* *Journal of the American Foundrymen's Association*, vol. ix.

† *Journal of the Franklin Institute*, vol. cl. pp. 227–237. See *Journal of the Iron and Steel Institute*, 1900, No. I. p. 363.

Combined Carbon.	Graphitic Carbon.	Si.	Mn.	S.	P.
2·60	0·72	0·71	0·110	0·045	0·039
0·82	2·75	0·73	0·108	0·04	0·039

The presence of silicon is necessary for the change of the carbon to be effected. When it is absent there is practically no alteration, however long the heating may be continued. Manganese also has an effect, which is, however, often masked by that of the silicon which it protects from oxidation rather than acting directly on the carbon like silicon. Iron low in silicon and manganese is practically worthless after annealing, as it is deficient in tenacity although it is softened. The carbon is changed to what Ledebur terms graphitic temper carbon. When it is not fully developed by over-annealing, it passes easily into the hardening condition.

H. O. Evans * discusses the shrinkage of malleable iron castings. The contraction in the casting is taken as ⅛-inch per foot, but during annealing expansion takes place to a variable amount, depending on the dimensions and on the time and temperature of annealing. Some general rules are given, but practical experience is the only true guide for the determination of the amount.

A note has appeared † giving the distribution and names of the firms making malleable castings in the United States, and also some general remarks on the manufacture.

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* Paper read before the Foundrymen's Association, April 4, 1900; *Iron Trade Review*, April 5, 1900, p. 7.

† *Engineering and Mining Journal*, vol. lxx. pp. 275–276.

PRODUCTION OF MALLEABLE IRON.

Manufacture of Best Yorkshire Iron.—E. Matheson * describes the manufacture of best Yorkshire iron at the Foundry Iron Works, near Leeds, with the aid of numerous illustrations. Clayband ironstone, containing about 33 per cent. of iron, is weathered and dressed, and then calcined to free it from shale. Coke made from the "Better Bed" coal is used, and also local limestone. For a ton of pig iron, 44 cwt. of ore, 30 cwt. of coke, and 11 cwt. of limestone are used. The blast-furnace is blown with cold blast at a pressure of 3½ lbs. Foundry test bars of the metal, 2 inches deep and 1 inch wide, on supports 3 feet apart, support 30 to 32 cwt. before breaking. The pig iron is then remelted on open fires and run into shallow chill moulds. It then has a fracture like spiegeleisen. The plates are broken up, and a charge of 336 lbs. of refined iron is puddled, coal being used as fuel. Two or three balls, weighing 90 to 160 lbs., are made per heat, and two or more balls are welded together under a steam-hammer to form blooms 4 to 5 feet long, weighing 160 to 300 lbs. These are rolled into bars, which are piled and hammered into blooms, or into slabs if plates are to be made. Tensile tests show 23 to 24 tons per square inch, with elongations of 30 to 40 per cent. on 4 inches, and 40 to 55 per cent. reduction of area.

The Stassano Method of Iron Manufacture.—Particulars are published † of the electrolytic method for the reduction of iron ore devised by Stassano. This consists in the use of an electric furnace, illustrations of which are given, in which the ore is heated between carbon poles. The ore, before being charged into the furnace, is first brought, if necessary, to the condition of an oxide, and is then mixed with exactly the quantity of charcoal required for reduction purposes, and of lime and silica for fluxing. The ore and these additions are made into a paste by the addition of some 5 to 10 per cent. of tar, and subsequently pressed into briquettes. It is with these briquettes that the furnace is charged. In one experiment quoted there was produced in 35 minutes 17½ lbs. of iron, at an expenditure of a little more than one hour horse-power per pound of iron made.

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* *Cassier's Magazine*, vol. xviii. pp. 179–187.

† *Journal of the Iron and Steel Institute*, 1900, No. I. p. 366; *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. pp. 340–341, with two illustrations.

John B. C. Kershaw * also describes the Stassano process for the production of iron and steel, which is being tried in Italy, and discusses the economy of the electric current when used for heating.

History of Iron.—The question when iron was first used was discussed by the celebrated Swedish archæologist Montelius at the thirty-first general meeting of the German Anthropological Society at Halle. Formerly it was generally believed that iron was not employed in the North, Scandinavia and North Germany until a very late date, about 900 A.D., and even within the last thirty years it has been thought that iron could not have been used in Scandinavia before 300 A.D. In Southern countries, however, iron was known at an extraordinary date. This was notably the case in Egypt, for it cannot be imagined that huge buildings, like the pyramids, could have been built without tools. Montelius is of opinion that in Egypt iron was not used before the middle of the twentieth century B.C. This view is supported to a certain extent by the new discoveries made by Flinders Petrie. One of the graves investigated by him dates back to 3000 B.C. In neither case was there a trace of iron discovered. Moreover, in Greece the earliest occurrence of iron was in the fourteenth century B.C. In view of the close relations with Egypt, so late a use of iron is inconceivable, if iron had been known in Egypt for thousands of years. Montelius concludes that iron appeared in Central Italy with the Etruscans about the year 1100 B.C. In Northern Europe it appeared soon afterwards. For example, it is found in the pile dwellings in Switzerland contemporaneously with bronze, and consequently for Switzerland and South Germany the tenth and ninth century B.C. may be taken as the starting-point of iron. Farther north, in a grave in Bornholm, iron dating from 1200 A.D. has been found.

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* *Electrical Review*, June 15, 1900.

FORGE AND MILL MACHINERY.

Electric Plant in Rolling-Mills.—Some illustrations have appeared * to show the power-house, the open-hearth charging machine, and the plate-mill driven by electricity at the Parkgate works, near Sheffield. The generating sets comprise two Westinghouse steam-engines, connected direct to two 200-kilowatt Westinghouse engine type generators. The engines are of the compound vertical type, and have cylinders 16 inches high pressure, and 27 inches low pressure in diameter by 16 inches stroke, and make 250 revolutions a minute. The dynamo current is at 250 volts pressure, the amperage being 1000. Steam is supplied by two 300 horse-power Lancashire boilers at 160 lbs. pressure. The dynamos are eight pole machines, compound wound, and of the open type. The generating sets are in duplicate, because one set is at present all that is required. Space is left in the power-house for a third set. The switchboard is placed centrally between the two generators.

The main plate-mill at Parkgate is a 36-inch mill, with a pair of roughing rolls 7 feet long, a pair of soft finishing rolls 12 feet long, and a pair of hard finishing rolls 8 feet long. The mill is driven by a 50-inch by 60-inch engine, with gearing in the ratio of 3 to 1. In this mill, as in the cogging department, the live rollers are all operated by 30 horse-power motors, and there are three sets of housings, with tables on both sides, requiring in all six motors. The skid gear is also operated by a 30 horse-power motor. The lifting and lowering gear is operated in each case by a 15 horse-power motor, running at 600 revolutions, geared down to 460 revolutions on the secondary shaft. The plate-mill wharf is served by a 5-ton electric crane, and also by a 10-ton rope crane, which, however, is shortly to be converted.

Some tests have been made on the consumption of power in rolling-mills for driving the live rollers by electromotors. In rolling a 9-inch joist from an ingot weighing 3300 lbs., the skid gear and live rollers in front of the finishing train used 18 horse-power running idle, and the power increased to 122 horse-power at the end of the operation, which took 327 seconds. Similarly on the live rolls in front of the roughing rolls the power ranged from 15 to 92 horse-power.*

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* *Iron and Coal Trades Review*, vol. lx. pp. 1181–1183.

O. Lasche † describes the copper rolling-mill at the Oberspree cable works near Berlin, where the roughing and finishing trains are driven by electromotors. The former has four stands, and is driven at 108 revolutions per minute by a three-phase motor through rope gearing. This motor gives 200 horse-power at 380 revolutions, taking current at 500 volts. The finishing rolls in seven stands are driven direct by a 400 horse-power motor, at 420 revolutions, a flywheel being provided. In eleven hours 27 tons of wire are rolled from bars 12·4 square inches in sectional area, and weighing 130 lbs. each; the wire produced being 0·275 inch in diameter. The mill has been at work for eighteen months. The author then discusses the size of three-phase motors required for rolling-mill work.

Modern Rolling-Mills.—E. Weber ‡ discusses the arrangements of modern rolling-mill plant, and makes suggestions as to the ways in which these could be improved. Some comments have appeared § on the design of roll-bearings and their lubrication. The researches of R. Job ‖ on bearing metals are especially mentioned.

Ehrhardt ¶ discusses some points connected with modern rolling-mill practice, considered especially with modern efforts to roll an ingot at one heat to the greatest possible length. Some modern forms of mills are dealt with.

P. Eyermann ** describes some modern American rolling-mill plants. These include one at Duquesne, Pennsylvania, and a modern plate-mill at Homestead, Pennsylvania. An older one at the latter place for large sections is also described.

P. Eyermann †† describes a continuous rolling-mill erected at Youngstown, Ohio. According to the shapes rolled, it can make up to 600 tons output daily, starting with small billets, and rolling them to hoop-iron used in binding cotton bales.

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* *Iron and Coal Trades Review*, vol. lxi. p. 314.

† *Technisches Centralblatt; Electrician*, vol. xlv. pp. 698–702.

‡ *Stahl und Eisen*, vol. xx. pp. 421–424, with three illustrations.

§ *Iron and Coal Trades Review*, vol. lxi. pp. 774–775.

‖ *Journal of the Franklin Institute*, vol. cxlix. pp. 439–450.

¶ *Stahl und Eisen*, vol. xx. pp. 871–874, with five illustrations.

** *Ibid.*, pp. 730–737, with five illustrations.

†† *Ibid.*, pp. 982–984, with an illustration.

A plan of the Lukens Iron and Steel Company's works at Coatsville, Pennsylvania, has appeared,* together with an illustrated account of the mill plant. The new steel plant includes six 50-ton open-hearth basic furnaces, with twenty-four 10-foot Talbot producers and a Wellman charging machine. The plate-mill is three-high, with rolls 134 inches long and 36 inches in diameter. A 48-inch universal mill capable of rolling plates up to 100 feet in length has been added. The upper and lower rolls are 28 inches in diameter, and the middle roll, which is movable, is 20 inches. The vertical rolls are 18 inches in diameter, with 12-inch journals. A Morgan electric charging machine serves this mill. The slabbing-mill has rolls 34 inches in diameter and 104 inches in length.

Three-High Rolling-Mills.—F. Horn † discusses three-high rolling-mills, largely from a mathematical standpoint. They possess many advantages over the two-high mill, but also disadvantages to which the author draws attention. They must necessarily have far more careful management.

Rolling Rails.—Further particulars are given ‡ of the methods and plant adopted for re-rolling worn steel rails. A magnet suspended from an overhead track picks up a number of the worn rails and transfers them to a charging table which runs on wheels, so that it can be brought in front of the reheating furnace. Hence they are charged into the furnace by a mechanical pusher; the details of this plant are illustrated. The hot rails are rolled first to diminish the height, and then they are turned on their sides to form them to the right section. Illustrations are given of the rolls and of the live roller tables and turning appliances used for these purposes.

In some notes § on the manufacture of rails at the present day, it is pointed out that the blast-furnaces are driven at a higher rate of speed. The metal, when reduced, is run fluid into a "mixer," but is never allowed to come to rest or cool. From the mixer it goes still fluid to the converter, and is blown in less time than before and in larger amount. It is then cast into ingots, which are not allowed to cool or come to rest, but are at once charged into heating furnaces, and held there until ready for blooming. They are then with their contents in an unknown state, sometimes fluid, semi-fluid, pasty, or granular, passed to the blooming-mill and reduced from 16 or 18 inches, an average modern-sized ingot, having 288 square inches of area, to a bloom 8 inches square, having 64 square inches of area, which is a reduction of 224 square inches in 11 passes, or 20·4 square inches of reduction to each pass, instead of 11·3 as formerly, which is nearly 100 per cent. faster; in addition to which the train is now-a-days driven at a higher rate of speed than formerly. The 8 by 8 inch bloom thus produced is not allowed to cool, but is charged into a heating furnace and held hot, or in some cases proceeds without further heating direct to the rail-mill, where it is reduced to a 70-lb. rail in nine passes instead of 13, by rolls running 900 feet per minute, instead of 400 as formerly, which is over 60 per cent. more rapid reduction, pass for pass, leaving out of consideration the speed at which it is done, which has an important bearing on the final result. Owing to all this haste, the rails finish at a high temperature, and the heads practically anneal and soften on the cooling beds. As the size increases, the difficulty of controlling the finishing temperature also grows, and it has been suggested that the rails should be passed through an additional furnace to equalise the temperature in the head and foot before the finishing passes, and thus to ensure a proper finishing temperature.

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* *Iron Age*, July 26, 1900, pp. 1–6.

† *Stahl und Eisen*, vol. xx. pp. 875–877.

‡ *Iron and Coal Trades Review*, vol. lxi. pp. 121–123.

§ *Ibid.*, pp. 355–356.

Nickel steel railway rails have been rolled for the Pennsylvania Railroad Company, and laid on the west track of the famous horseshoe curve near Altoona. A letter from W. H. Brown,* the chief engineer of the Company, gives the following details of this installation. The order for 300 tons of 3 per cent. steel rails was placed with the Carnegie Steel Company on June 26, 1899. The steel was made by the Bessemer process, and the rail was rolled to the 100 lbs. Am. Soc. C. E. section. In rolling, the nickel content caused "red shortness" to such an extent that the rolling resulted in only 220 tons of No. 1 and 57 tons of No. 2 rails, and 19 tons of the latter had to be thrown away because of piping. The average analysis was as follows:—Carbon, 0·504 per cent.; phosphorus, 0·094 per cent.; manganese, 1 per cent.; and nickel, 3·22 per cent. Under the straightening presses the rails showed great rigidity, twice the force ordinarily used being required to accomplish the cold straightening, and often the rail would spring back to its former position after being struck. In drilling, the hardness was even more marked, in some cases five twist drills of ordinary tool steel being used up in drilling one hole. After experimenting with different materials for drills, it was found that the best results were obtained by using Mushet steel drills without lubrication. The rails have not been in service long enough to afford any record of their wearing qualities.

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* *Railroad Gazette*, vol. xxxii. p. 195; *Engineering News*, vol. xliii. p. 217.

Some discussion as to the first rail rolled in America has taken place between C. Lewis and R. W. Hunt.*

Wire-Rod Mills.—A plan and some illustrations have appeared of the new-wire rod mill plant of the Ashland Steel Co., Kentucky. Steel is made in two 5½-ton converters, having a capacity of 500 tons, in twenty-four hours. Ingots are cogged in a 32-inch blooming-mill, and the sheared billets are taken by a wire rope conveyor direct to the reheating furnaces of the Allen continuous type. The roughing train has eight passes, and the rod is finished in a Garrett-Cromwell continuous looping-mill with automatic revolving reels. This mill has five sets of rolls in the 12-inch intermediate train, and six sets in the finishing train. A wire rope conveyor removes the coils from the reels.†

W. Hirst ‡ discusses the design of passes in mills for rolling wire rods. In that operation the determining factors are the form of the pass, the nature of the metal, and the temperature of the work. With low carbon steel, the maximum draft on a 3-inch billet is about 1·75 to 1, and on the smallest or finishing pass, not more than 1·15 to 1. In the usual practice a billet 4 inches square, and weighing 100 to 200 lbs., is reduced to No. 6, B.W.G. in 18 passes; and a table is given to show the form and size of the alternate square and oval passes used, together with the reduction and other factors.

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* *Iron Age*, September 20, 1900, pp. 18–20.

† *Iron Trade Review*, June 28, 1900, pp. 12–15.

‡ *Iron Age*, May 10, 1900, pp. 14–17.

PRODUCTION OF STEEL.

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I.—*THE CARBURISATION OF MALLEABLE IRON.*

Direct Production of Steel.—The Rudolphs-Landin method for producing steel direct from the ore is described in a recently published pamphlet.* The ore, in a more or less fine state of division, is mixed with carbonaceous and binding material, and also with any fluxing material that may be required. The mixture is compressed into briquettes and passed through a long furnace, in which they are first dried, and then the oxide of iron is reduced to a sponge of metallic iron. The reduced briquettes are then dropped direct into a bath of molten metal, which is kept covered with slag. Preferably a 20-ton tilting-furnace is used, and a portion of the bath is withdrawn at intervals of about four hours. This metal is transferred by a ladle to a steel furnace of the open-hearth type, and there finished. A sketch plan of the suggested plant is given, while the thermal requirements and possible advantages of the process are discussed by H. Tholander and P. Hördén.†

The Sands Employed in Casting Steel.—A. Coroux ‡ describes the sands used in casting steel. Among the natural materials used for this purpose the author enumerates, in the first instance, powdered quartz, obtained by heating quartz to a high temperature and then plunging it into cold water. After such treatment it can be readily powdered. It is typical of moulding sands, and contains 99 per cent. of silica. The sands of Voreppa, Plat-de-Giers, and Saint-Egreve are next mentioned. They are used in connection with crucible or small converter plants, and form, too, a very good material for use in lining acid converters. They contain :—

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* A copy is in the Library of the Iron and Steel Institute.

† *Teknisk Tidskrift*, vol. xxx. pp. 60–64.

‡ *Bulletin Technologique*, 1900, pp. 816–820.

SiO_2.	Al_2O_3.	CaO.	MgO.	Fe_2O_3.	Loss.
84·5	8·5	0·7	0·3	3·1	2·9

The Fontenay sand, which usually fetches a high price, contains :—

SiO_2.	Al_2O_3.	MgO.	CaO.	Loss.
85·2	7·8	0·6	0·7	5·7

The sand from Ougrée in Belgium can be used almost without any preparation, and contains :—

SiO_2.	Al_2O_3.	CaO.	MgO.	Fe_2O_3.	Loss.
92·0	4·02	0·6	0·4	1·38	1·6

Amongst clays, &c., which may enter into the composition of moulding sands for steel, the author enumerates kaolin; that from Bollène, whose composition is :—

SiO_2.	Al_2O_3.	CaO.	Loss.
53·0	37·0	1·0	9·0

and a number of others. Their price is less than that of the sands. It is pointed out that sands which are suitable for use in casting pig iron are not generally suited for use in casting steels, which are often run at a much higher temperature than is the cast iron. They contain, too, more gas, and this being given up at the moment the steel is cast, gives rise to explosive effects if care has not been taken to have a sufficiently porous mould. Usually the mould is made of a mixture of sand and clay, the percentages used being very variable according to the nature of the materials dealt with. Practical men can tell at once by the touch whether a sand is suitable for moulding purposes.

The Manufacture of Special Steels.—L. Babu, in a paper at the Paris International Congress on Mining and Metallurgy, discusses the manufacture of special steels, under which heading those containing such elements as chromium, nickel, tungsten, and silicon are included. Many researches have been made on these bodies, but are very generally kept secret; some particulars are, however, available. The critical points are considered in some detail. The changes in the chemical composition are so intimately connected with the critical points of carbon steels, that it is probable the same holds good as regards special steels, but our knowledge at present with regard to this matter is defective. As stated before, in the special steels carbon to a certain degree is always also present. With manganese steel it is found that the critical points of the alloy vary with the varying proportions of these two constituents, and the presence of manganese retards the magnetic transformation and lowers the point of recalescence. In nickel steel the addition of 5 per cent. of this metal to carbon steel lowers the point of recalescence 300°. The phenomenon of hysteresis in the case of nickel steels assumes an abnormal and excessive character. With 4 per cent. there is a difference of 100°. These steels, therefore, are termed "irreversible" alloys. In chrome steel carbon is always present to a relatively considerable extent, and the critical points are found to correspond to those of carbon steel. The same remark holds good with regard to tungsten steel. When the latter is suddenly cooled at a temperature above the critical point, it presents the properties of hardened or tempered steel. In silicon steel the constant presence of manganese prevents us judging the influence of silicon on the critical point. The manufacture of the special steels in large quantities in the open-hearth furnace is attended with many difficulties—notably in the case of chromium, which oxidises at a high temperature; hence metal-work with a higher percentage than 3 is not melted. Such is the composition of the chrome nickel steel used for ordnance or armour plates. Silicon steel is employed by many works for making springs. Bessemer metal is welded easily, and has a temperature 200° or 300° higher than open-hearth steel, so that, with the aid of a converter of a capacity of one or two tons, founders have succeeded in producing castings weighing from four to five tons—by accumulating the charges in a receiver. With a converter of twelve tons, castings up to thirty tons could, if required, be easily made. The manufacturers of machinery, bicycles, motor-cars, &c., demand from the steel-foundries thousands of small pieces which formerly were forged or made of cast iron. The industry of steel bells has, indeed, not developed, since they conflict with the tradition that bells should be of bronze, nevertheless the former are cheaper and more solid, and, above a certain weight, comparable with the latter in tone. The Alexander III. bridge at the Paris Exhibition is constructed of cast steel. In engineering, the application of steel plates for hydraulic cylinders, boilers, &c., is extensive; steel shafts are now cast as strong as those of forged steel; machine frames and steam-cylinders twice as light, twice as strong, as cast iron; geared wheels, pistons, cranks, cylinder heads, &c., are now made of cast steel. The extension of electric machinery has been greatly aided by the production of cheap steel castings; the dynamos are lighter and less cumbersome, and require less copper on account of the reduction in the size of the coils. The annual production of steel castings has risen from 30,000 tons in 1889 to 200,000 tons at the present time, and it is not to be doubted that the industry will receive a still further extension.

II.—*THE OPEN-HEARTH PROCESS.*

A New Form of Open-Hearth.—A new form of open-hearth is described by von Zeipel* and Björndal. The producer gases enter at the upper parts of the regenerator chambers, pass down through these, and are then led upwards through channels into the furnaces. The settlement of slag and dust in the regenerator chambers is in this way avoided.

Charging Apparatus for Open-Hearths.—An electrically driven charging apparatus for open-hearths, constructed by a German firm, is illustrated.† Three of the forms illustrated are already in operation, and are stated to give complete satisfaction. Another apparatus for the same purpose is also described.‡

Recent Improvements in Steel Manufacture.—F. Lürmann, jun.,§ refers to the objections which have from time to time been made against ingot metal, and especially basic steel, as a material for use for construction purposes, and he shows that these have no basis of fact. Now-a-days one knows exactly what composition is the best for pig iron that is to be used for the basic process. Formerly this was not the case. Then, too, the use of pig iron mixers is a great improvement by ensuring uniformity of composition and partial desulphurisation. These are naturally the more perfectly effected the longer the pig iron remains in the mixer, but this is accompanied by loss of heat by radiation. This affects the loss of metal and the duration of the blow just as changes in the chemical composition do. This is avoided by the use of mixers that are heated, mostly in use in the United

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* *Wermländska Annaler; Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. p. 422.

† *Stahl und Eisen*, vol. xx. p. 996, with one illustration.

‡ *Ibid.*, pp. 748-749, with four illustrations.

§ *Ibid.*, pp. 769-787, with illustrations.

States. To such a mixer additions of scrap, spiegeleisen, and other varieties of pig iron can be made in the solid state without any deleterious effect. An automatic registering pyrometer gives the exact temperature of the escaping products of combustion, air and gas being thus completely under control. While the ordinary charge for a converter a few years ago was 7 to 12 tons, now-a-days charges of from 12 to 20 tons are preferred. Large charges mean greater uniformity of product. The converters themselves, and their linings and bottoms, have of late years been very greatly improved. The author considers the addition of ferro-manganese in the ladle not to be a satisfactory method of making such addition. It is not necessary, either, to allow metal to stand in the ladle before casting. A thorough admixture has been ensured by the pouring of the metal from the converter into the ladle. The author has proved this by a number of comparative assays.

A series of curves are shown relating to a 100-ton mixer used for pig iron. The phosphorus showed on standing a diminution of 0·02 per cent. with metal containing about 1·8 to 2 per cent. of phosphorus; a loss of 0·03 per cent. of silicon with metal containing about 0·15 to 0·5 per cent. of silicon; while the sulphur diminished by about 0·04 per cent., the original metal containing mostly less than 0·1 per cent.

In dealing with the open-hearth process the author considers the introduction of movable furnaces to have been a marked improvement. He also deals with the duration of the charge in the furnace, and recommends rapid working. Rolling-mills and soaking-pits are referred to, and methods of casting steel considered. The liquation within the ingot and the heads in casting are briefly mentioned. The liquation takes place more readily and completely in larger ingots. A slight addition of silicon or aluminium tends to prevent the liquation. Great stress is laid by the author on the value of etching tests. The value of properly theoretically trained individuals in controlling the work of the practical man is also shown. The author next considers the influence exerted by various elements, such as silicon, oxygen, and phosphorus. Oxygen he considers to be a far more dangerous enemy to steel than is phosphorus. A lengthy and important discussion ensued on the reading of this paper.

The Tilting Open-Hearth Furnace.—H. M. Howe,* on the authority of S. T. Wellman, states that a fore-hearth or casting-shoe has been attached to the tilting furnaces at Ensley, Alabama. Ladles can thus be dispensed with, the metal need not be so hot when pouring, and slag difficulties are diminished.

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* *The Mineral Industry*, vol. viii. pp. 378–379.

P. Eyermann * refers to the various forms of movable open-hearth furnaces. These include the Wellman and Campbell-Aiken, and another form which the author has seen at work in the United States. One such is in use at the Pencoyd Ironworks, with a capacity of 100 tons, while four 50-ton furnaces of two kinds are in use at the Cleveland Rolling-Mills, while others are in use elsewhere. The author thinks only the smaller 4 to 10 ton furnaces would be advisable for use in Europe for steel-casting purposes. That these would be of use is due to the fact that fresh hot steel can be constantly charged into the casting ladle—an important matter in the case of foundries where many small castings have to be made.

For a 70-ton furnace the author considers the Wellman type the best. The modern American form of tipping open-hearth has the disadvantage that there is a great waste of heat, and large quantities of fuel are consequently consumed. The author considers that an improved type would be represented by a combination of the Wellman and Campbell-Aiken forms, and that the tipping open-hearth only presents advantages over the fixed form in the case of furnaces of from 4 to 10 tons or of over 50 tons capacity. The 100-ton tipping furnace at the Pencoyd Works is worked continuously, about 70 tons being poured off and the remainder allowed to remain in the furnace for the next charge. An important matter for the manufacturers of basic open-hearth steel, both in the United States and in Mid-Europe, consists at present in obtaining large quantities of the necessary scrap of good quality. This is frequently so dear as to make the commercial success of the works using it a matter of much difficulty. It is readily to be understood, therefore, how the tendency of the steelworks manager is naturally to trend back to a preliminary partial treatment of the pig iron. Many works make excellent steel now-a-days by combining a preliminary Bessemerising with a subsequent open-hearth treatment, a great saving of time in the open-hearth being the result. The author asks why this method should not be carried much farther still, and he considers the tipping form of the open-hearth to be excellently suited to such a mixed process. He also shows in what way an open-hearth possesses advantages over a Bessemer converter, and, similarly, how the output in the latter method greatly exceeds

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* *Stahl und Eisen*, vol. xx. pp. 310–315, with two illustrations.

that in the former. It is this that has probably caused the Bessemer process to hold its own so well. The author illustrates a form of combined converter and tipping open-hearth. This consists of a tipping open-hearth provided with tuyeres at the side. When it is desired to subject the pig iron to a preliminary treatment for the open-hearth method, the furnace is tipped so as to allow the blast entering through the tuyeres from the blast-furnace main to come into action. The furnace can be subsequently turned up again, the blast stopped, and the ordinary open-hearth method be proceeded with.

The Continuous Open-Hearth Process.—H. M. Howe* describes the Talbot process, and discusses its various features in some detail under the following headings:—The furnace, procedure, advantages, waste in melting down, maintenance of sides, bottoms, and roof, wider range for composition of pig iron, rapidity of operation and re-phosphorisation. The Bertrand-Thiel process is also compared.

Verney † also describes the Talbot open-hearth steel process.

In a letter recently published ‡ a comparison is made between the two processes, the Bertrand and the Talbot. Both deal effectively with molten pig iron, and rely for successful operation on reduction of iron ore by means of the metalloids in the pig iron. For the capital involved, the Bertrand process seems to produce a good deal of steel; from the figures available nearly three times as much. The labour cost therefore is less. The Bertrand process produces a highly phosphoric slag, which is valuable, while the Talbot process produces a lean slag, which is not of great value. The Bertrand process shows a gain of 2 to 3 per cent. in yield on materials charged, while the Talbot process shows a gain of 5 to 6 per cent. The Bertrand process admits of the use of the fore-hearth, recently so successfully introduced in America, which obviates the necessity of the costly and treacherous ladles and stoppers. The Talbot process necessitates the use of a ladle. On the other hand, the Bertrand process delivers its full charge at once to the mills, while by manipulation the Talbot process can give a more continuous supply of ingots. Further discussion has ensued.

Joseph Hartshorne § gives some further notes on the Bertrand-Thiel process.

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* *The Mineral Industry*, vol. viii. pp. 368–378.

† *Comptes Rendus Mensuels de la Société de l'Industrie Minérale*, 1900, pp. 62–65.

‡ *Iron and Coal Trades Review*, vol. lxi. pp. 178, 211.

§ *Transactions of the American Institute of Mining Engineers*, February 1900.

An estimate is given * of the cost of the Bertrand-Thiel process using all pig iron and 70 per cent. pig iron, as compared with the ordinary process.

Basic Open-Hearth Process.—The present condition of the manufacture of basic steel and its influence upon that of puddled iron is discussed by G. Rocour in a paper before the Paris International Congress on Mining and Metallurgy. The development in the manufacture of basic-lined furnaces is dealt with generally, and the following conclusions are given:—

1. The iron manufacture will be continued, on a progressively reduced scale, for working up iron scrap into bars of small section and for special purposes, so long as steel does not too greatly predominate in the quantity of crop ends and other scrap, or the competition of open-hearth steelworks does not too greatly enhance their price.
2. Puddling will become restricted and tend to disappear much more rapidly if coal remains dear and puddlers become scarce; but so long as competition between steelworks does not reduce prices to their minimum, puddling will still be practised.
3. After a fall in prices, which will certainly happen so soon as steelmakers cease to work in concert, the manufacture of current rolled products will have a tendency to become concentrated in a few large basic steelworks that are under favourable conditions as regards ore or coal.
4. The acid open-hearth process will retain a monopoly for high-quality products, but will not be able to compete commercially with the basic process for products of every-day use.

Canadian Steel Plant.—The first steel plant in Ontario, Canada,† was started about June 1, 1900, by the Hamilton Steel and Iron Company, at Hamilton. It consists of a blast-furnace, 17 by 75 feet, originally owned by the Hamilton Blast-Furnace Company, and open-hearth plant, containing two 16-ton Wellman rolling open-hearth furnaces, with an electric charging machine with four 10-feet Talbot water-sealed gas producers, and a rolling-mill containing one 14-inch and one 10-inch train for rolling merchant bar, small angles, and other shapes.

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* *Iron and Coal Trades Review*, vol. lxi. p. 576.

† *Iron Age*, July 5, 1900, pp. 7-9, with illustrations; *Iron and Coal Trades Review*, vol. lxi. pp. 210-211.

Australian Steel Plant.—It is stated * that the first open-hearth steel furnace in New South Wales was started on April 26, 1900, at the Eskbank Works, Lithgow. It is a 5-ton furnace.

New American Open-Hearth Plant.—Plans and illustrations have appeared † of a new open-hearth plant at Newburg, Ohio. A similar plant has also been erected at Worcester, Massachusetts. One clear span 54 feet wide and 391 feet long covers four Wellman tilting furnaces and leaves room for a fifth, while a lean-to 35 feet wide covers the charging floor. Each furnace has a capacity of 50 tons. Two lines of crane girders carry two ladle cranes each of 75 tons capacity, and the furnaces can be poured into the ladle or through a fore-hearth into the moulds direct. The cranes also command the furnaces, so that the removable ports can be readily charged. The charging platform carries four lines of rails for the charging-box trolleys and the Wellman charging machine. In the rear is a line of fourteen gas producers 12¼ feet in diameter.

F. Lürmann, jun.,‡ describes the Apollo Open-Hearth Steelworks and rolling-mills situated at Poulton, near Pittsburgh. This work possesses three 30-ton acid open-hearths, the steel from which is rolled into sheets. It contains :—

Carbon.	Manganese.	Silicon.	Phosphorus.
0·115–0·130	0·30–0·36	0·24–0·25	0·064–0·112

At the time of the author's visit in November 1898, these works, he says, were generally considered to be the best arranged of their kind in the United States. He describes them in detail with the aid of numerous illustrations.

An illustrated detailed description of the open-hearth steel plant of the Alabama Steel and Shipbuilding Company at Ensley, Alabama, has been published.§

III.—*THE BESSEMER PROCESS.*

The Working of Bessemer Converters.—In the annual report of the Chief Inspector of Factories and Workshops, a report by H. P.

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* *Sydney Morning Herald*, April 26, 1900, through the *Iron and Coal Trades Review*, vol. lx. p. 1137.

† *Iron Trade Review*, July 5, 1900, pp. 12–14.

‡ *Zeitschrift des Vereines deutscher Ingenieure*, vol. xliv. pp. 1324–1327, with 12 illustrations.

§ *Iron Trade Review*, August 23, 1900, pp. 11–14.

Smith deals with the use of safety appliances or locking valves for Bessemer converters or centre cranes.

The Tropenas Process.—A plan and illustration of the Tropenas converter plant, erected at Chicago Heights, Illinois, has been published.* There are three 2·4-ton converters, supplied from two cupolas. The metal is poured into ladles and distributed into smaller pouring ladles for making castings.

These converters are also † in use at a works at Phœnixville, Pennsylvania.

Steelworks in the Minette Ore District.—A series of articles have appeared ‡ dealing with the various iron and steel works in the Minette ore district of Lorraine, Luxemburg, and France. At the Rombach works four old furnaces and one new furnace are in blast, and two new ones are being built, 82½ feet high, with 23-foot boshes, to make 180 to 200 tons daily. Blast-furnace slag is granulated and made into bricks. There are two 200-ton mixers, four 17-ton basic converters, and three 25-ton open-hearth furnaces. At the Lothringen Aumetz Friede works at Knenttingen, three out of six furnaces are at work, and there are four 20-ton converters. At the Differdingen works there are four furnaces, and a fifth is to be built. A Uehling casting-machine is at work, and there are two 250-ton mixers. At Homecourt are six furnaces and four basic converters. The rolling-mill and other plant at all these works is also described.

New American Bessemer Works.—A plan and some illustrations have appeared § of the Youngstown Bessemer plant of the Republic Iron and Steel Company. The iron is melted in four 24-inch cupolas and converted in two 5-ton vessels. Truck ingot moulds are used. Billets, &c., are made in a 32-inch blooming-mill.

The water-softening plant at the Lorain Steel Company's furnaces is described by N. O. Goldsmith.|| It consists of four tanks, each holding 95,000 gallons, in which the water is mixed with caustic lime and soda ash.

A Chinese Steelworks.—F. Lynwood Garrison ¶ describes the Han-yang Steelworks, near Hankow, which was initiated about six or

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* *Iron Trade Review*, September 13, 1900, pp. 14–15.

† *Iron Age*, September 27, 1900, p. 7.

‡ *Ibid.*, July 5, 1900, pp. 10–12; July 12, pp. 2–5.

§ *Ibid.*, October 11, 1900, pp. 16–17.

|| *Transactions of the American Society of Mechanical Engineers*, vol. xxi. pp. 874-892.

¶ *Iron Age*, September 13, 1900, pp. 1–2.

eight years ago by Chang-chi-Tung, under the auspices of the Chinese Government. It lies on the banks of the Yangtse, and within easy reach of the Taye mines, from which the ore is brought by a fifteen-mile railway to a point on the river only forty-five miles from Han-yang. The ore deposits at Taye are extensive, and the quality is excellent, the ore being mostly magnetic, and containing on an average 63 per cent. of iron and only 0·05 to 0·08 of phosphorus. The Japanese are now resorting to these mines for the supply of ore for the steelworks at Wakamatsu, near Moji, Japan. The chief drawback at Han-yang is the scarcity of coke, though an enormous quantity of good coal can be obtained in or near the Yangtse Valley. The plant comprises a blast-furnace equipment, puddling furnaces, and rolling-mills, two Bessemer steel converters, an open-hearth plant, rail-mills, machine shops, foundry, &c., fairly complete and modern in most respects at the time of installation. The two blast-furnace stacks are 64 feet high. With good coke these furnaces will, it is claimed, produce from 75 to 80 tons each per day, but as the coke ordinarily used is poor, the average production is not over 60 tons. There are twenty single puddling furnaces of the usual size, and built in groups of four, the waste gases being used to heat a vertical boiler. Five-hundredweight charges are treated in each, and the blooms are worked under two 3-ton steam-hammers, and passed through a 20-inch train of roughing rolls. Sheet-mills are supposed to be included in the plant, but do not appear to be in operation. The two Bessemer converters are of 5 tons each, and there is one 12-ton open-hearth furnace of ordinary construction supplied by four Wilson gas-producers. The rail-mills are of no special interest. The foundry has a 20-ton travelling crane and three cupolas.

The Manufacture of Basic Slag.—A report by H. P. Smith upon the conditions attending the crushing of basic slag appears in the report of H.M. Chief Inspector of Factories and Workshops, from which it appears that the crushing is done by one of the following systems:—(1) In Krupp ball, otherwise known as "Herm Lohnert," mills. (2) By the edge-runner system. (3) By ball-mills, with cylindrical pebble mills used as auxiliaries. (4) By a combination of edge-runners, rollers, and separators. The effect of the recommendations made by the Dangerous Trades Committee are dealt with at some length.

Cupola Practice in Bessemer Steelworks.—According to S. M. Rogers,* there is no essential difference in the construction of the cupola used in the Bessemer steelworks and the cupola used in ordinary foundry practice, but the lining near the bottom is made 24 to 26 inches in thickness when it has to run for a week, and even thicker when 1 per cent. or more of manganese is present in the pig iron. The tuyeres are placed higher than usual, so as to leave sufficient space in the well. A 48-inch cupola will have 48 to 50 tuyeres, tapering from 4 to 2½ inches in diameter, and a volume gauge should be provided to measure the blast, which may have a pressure of 4 to 7 ounces per square inch. Limestone is used as flux, varying from 35 to 40 lbs. per ton of metal.

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* *Journal of the American Foundrymen's Association*, vol. ix. Part i. pp. 40–46.

FURTHER TREATMENT OF IRON AND STEEL.

The Manufacture of Steel Castings.—In a paper read at the Paris International Congress on Mining and Metallurgy, A. Tissot* deals with the present condition of the manufacture of steel castings. It is fifty years since the first steel castings were made, but until quite recently the production was very limited, owing to the difficulty of obtaining the liquid metal in sufficient quantities for making very large castings. Attempts were made at the time of their first appearance to utilise the Bessemer converter and the open-hearth furnace, but not with good results. About 1885 Robert invented his converter with side blast, which, applied to the casting of steel, enabled the works to produce complicated castings of excellent quality, and, in fact, created a new industry, for the sphere of their utility has been extending ever since. Many difficulties have, however, had to be surmounted by the steel-founders, and it is only in virtue of their perseverance and ingenuity that the new craft has become a success. The melting-point of steel is very high, ranging from 1450° to 1500° C., and in working the metal still higher temperatures are employed. This high melting-point, and the contraction which steel undergoes when it cools, were the source of much vexation to the steel-founder. This shrinkage amounts to from 1·5 to 1·8, or even 2·0 per cent., according to the heat and composition. If the mould offers too great a resistance to this contraction, there is a risk of the casting cracking or becoming crooked. The third source of anxiety was the appearance of flaws, because it is necessary that a steel casting should be perfectly sound. The united efforts of the manufacturers of steel and of the founders have, however, overcome every difficulty. After many experiments, it was discovered how to prepare a suitable refractory sand, capable of withstanding the intense heat of the molten metal. It is composed of quartz sand, silica brick pounded, and other refractory material, and it is rendered plastic by the addition of clay. The great shrinkage that steel experiences on cooling has most severely taxed the resources of the founder, and he has only been able to remedy its consequences by a number of contrivances, such as the introduction of ribs to strengthen dangerous parts, the early removal of the core which opposes the contraction of the metal, releasing the casting while it is still red-hot, &c. With the facility of obtaining a regular supply of metal, the steel-foundries proceeded to improve their plants; the old cranes were replaced by electric or steam-lifting machinery of a power of 30, 50, and 100 tons; cold saws, compressed air machine tools, and electric welding for remedying slight superficial defects, were introduced; and lastly, as denoting the great extension of the industry, the moulding machine was adopted in steel-foundries. The converters, with a lateral blast, supplying steel at a very high temperature—which can be stored without becoming too cold to run into the mould—enables the founder to turn out, with the aid of the machine worked by two men up to a ton per day of complicated castings weighing from 10 to 40 lbs. each. Another great improvement effected is the subjecting the pieces during annealing to a sudden cooling or tempering in air, which improves the quality of the steel. The castings are heated to 1000° C., and then suddenly exposed to air at from 1000° to 600° C. Their power to resist shocks is thereby vastly increased, and they are more elastic and more tough. Improvements in the construction of the crucible furnace, and the higher temperature now obtainable, enable very delicate and malleable castings to be made at the present time with a metal containing a much lower percentage of carbon than was formerly possible. Sundry correctives to the steel, such as aluminium, nickel, &c., are now added. The ameliorations made in the open-hearth furnace during the last ten years have greatly assisted the founder. The temperature, quality, and purity of the metal have been improved. Acid metal is no longer necessarily hard as formerly. Basic furnaces have now been brought to such perfection that with their produce excellent castings can be made which ten years ago was impossible. The judicious employment of aluminium is responsible for this improvement, so that basic steel is in many cases now preferred to acid steel. The increased employment of cast steel has led to the construction of furnaces of a capacity of 50 tons which are as reliable as those of 21 tons, and they are specially devoted to the production of steel for castings, and only rarely are ingots run from them. The converter, with the lateral blast of Robert, or its imitations, has now come into general use, and seems to satisfy all the remaining requirements of the steel-founder. Owing to the peculiar arrangement of the tuyeres, the output can be varied from 0·8 to 2 tons, or from 3 to 4 tons in the two types of the apparatus in use. The metal is milder than that produced by the open-hearth furnace. It possesses great power of resisting shocks and a degree of elasticity which attains 69·8 tons per square inch; it is, therefore, naturally well adapted for war material and marine purposes. Nickel steel with varying proportions of the first-named metal is now also largely manufactured for armour-plates, artillery, &c. The first special steels which were introduced, such as chrome and manganese steel, did not produce any greater difficulties in working than ordinary steel. The conditions in forging, tempering, and annealing were much the same as in carbon steel. Later varieties, notably those with a large admixture of nickel, owing to their extraordinary properties, presented difficulties of a formidable nature. Certain steels at the temperature at which carbon steel can be forged become hard. In others, the process of annealing seems to have an action the very reverse of that it has on ordinary steel, and so forth. It required innumerable experiments and much scientific research to arrive at suitable methods of working the new alloys. According to the theory of Curie, steel should be tempered when it is in a feeble magnetic condition at a high temperature. The determination of the point of magnetic transformation would be sufficient, therefore, in any case, to determine the temperature suitable for tempering. Before the new alloys—notably nickel steel—could be introduced into practical industry, many difficulties had to be overcome, owing to their extreme hardness, which the drills, the cutters of the planing machine, &c., could not attack. However, by annealing the metal and the use of specially made tools, and by working at a reduced speed, the trouble has been overcome. The metal adopted at the works of Imphy for machine tools is chrome tungsten steel tempered.

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* *Iron and Coal Trades Review*, vol. lx. pp. 1228–1229.

An account is published of the life of J. Mayer,* who is stated to have been the originator of steel castings. Though steel had long been known, yet only those of its properties were fully understood which it possessed in common with wrought iron, until in 1851 Mayer showed that this metal could be used in a similar way to cast iron, all attempts at which had up to that time been failures. The subsequent progress of the invention is passed in review, and it is pointed out that its originator, great though his work was, is now almost forgotten.

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* *Zeitschrift des Vereines deutscher Ingenieure*, vol. xxxxiv. pp. 1368–1371.

A Twenty-Ton Casting Ladle.—Illustrations are published [*] of a twenty-ton casting ladle made at the Tigler Works, Meiderich, for an ironworks in Lorraine.

Ladle Carriage.—An illustrated description is given [†] of two carriages, one operated by steam and hydraulic power, the other electrically, for transporting and pouring ladles containing molten metal.

Repairing Faulty Castings.—Further details are given [‡] as to the application of the Goldschmidt method. The process readily admits, it is pointed out, of application in the repair of faulty castings. Another possible application of the process is also referred to in connection with armour plates. [§]

Goldschmidt's rail-welding process is described by Goldschmidt and Beyer. [||]

S. B. Archdeacon [¶] gives some notes on the generation of intense heat by the combustion of aluminium, and refers to its use for the production of chromium, titanium, &c., and their alloys with iron; and also to the use of the mixture of aluminium and ferric oxide for welding purposes. The latter process is described in detail, and a table is given to show the sizes of articles, such as bars and pipes, that can be welded, and the dimensions of the moulds and crucibles, and the amount of the mixture to be used.

Removing the Burr from Angle Iron.—An illustrated description is published of a German machine designed for the removal of the burr from angle iron, manufactured by Breuer, Schumacher & Co. Such a machine has been used with success for a considerable time at Rothe Erde Steelworks. [**]

A New Tool Steel.—At the Vincennes Annexe of the Paris Exhibition the Bethlehem Steel Company of Pennsylvania exhibited a new tool steel which accomplished some remarkable results. When the members of the Iron and Steel Institute were in the building it was employed to turn a mild steel shaft, and the cutting speed was 150 feet per minute. The tool worked dry, and the cuttings became so hot that a thin tongue of red-hot metal flowed away from under them, and when cool they assumed a deep blue colour. In some cases the surface of the turnings was even partially fused. The steel is prepared by a special process of tempering and heat treatment, of which details are not available.

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[*] *Stahl und Eisen*, vol. xx. pp. 643-647, with three illustrations.

[†] *Ibid.*, pp. 643-647.

[‡] *Ibid*, pp. 567-570, with two illustrations.

[§] *Ibid.*, p. 612.

[||] *Street Railway Journal*, February 1900, pp. 158-159.

[¶] *Engineering and Mining Journal*, vol. lxx. pp. 219-223; see also E. F. Lange's paper in the present volume.

[**] *Stahl und Eisen*, vol. xix. pp. 1107-1109, with two illustrations.

Results[*] of tests of tools treated by the so-called Taylor-White process have been published.

Reheating Furnace.—In a new form of furnace, designed by Wellman, Daniels, & Wellman to supersede the soaking-pit, the ingots are charged vertically into a long furnace in which they are pushed towards the hot end. They rest on water-cooled pipes, and are prevented from falling over sideways by similar pipe guides. The furnace is thus intended to be of the continuous type.[†]

At the Kulebaki Ironworks, Russia, a reheating furnace for ingot iron sheets has been erected by J. O. Rayner.[‡] Of this a description and illustrations are now given.

Steel for Cycles.—D. Flather[§] describes the manufacture and treatment of steel used for cycle construction. The harder kinds of steel require proper annealing, and for good results much depends on the temperature. It should be done on a rising, not on a falling temperature. Too frequent annealing is, however, objectionable. More mechanical work should be put into the steel to improve its quality.

Wire Rope.—Justin S. Doe[||] discusses the uses, abuses, and care of wire rope.

Tube-Making.—The Perrin process for making welded tubes is described.[¶] Puddled bars of trough section are produced and piled together into a tubular form, with the longitudinal abutting edges placed to break joint, and the pile is then rolled into a tube. A works is stated to have started this process near Wolverhampton.

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[*] *Engineering Record*, August 4, 1900; *American Manufacturer*, August 16, 1900.

[†] *American Manufacturer*, vol. lxvi. pp. 281–282.

[‡] *Stahl und Eisen*, vol. xx. pp. 472–474, with four illustrations.

[§] Paper read before the Cycle Engineers' Institute; *Ironmonger*, July 7, 1900, p. 9.

[||] *Mines and Minerals*, vol. xx. pp. 525–526.

[¶] *Iron and Coal Trades Review*, vol. lxi. p. 516.

E. Blum[*] describes the armoured pipe prepared by the Société Anonyme des Hauts-Fourneaux, in which additional strength is obtained by shrinking on strengthening rings. It is stated that in this way not only is the pipe strengthened, but should a hole be made in it, the tear can only attain small dimensions. These pipes have been considerably employed in connection with the water-pipe lines for the towns of Lyons and Paris. In the course of three years about 20,000 tons were made of this kind of pipe.

Railway Wheels.—A. Sailler[†] considers the question of wheels for railway use, and in particular the question of the connection of the tyre portion with the body of the wheel. The Königswald method is specially dealt with.

Structural Steel.—K. Riensberg[‡] describes at much length, and with numerous illustrations, the method of erecting fire-proof structures in the United States, and also gives details as to the materials used for this purpose.

Maurice M. Sloan[§] gives specifications for iron and steel work in buildings, and also gives a sample specification.

Modern Bridges.—Some of the more recently erected bridges in France are illustrated and described by Frahm.[‖] These include the Mirabeau Bridge at Paris, in the construction of which 2077 tons of rolled steel, 385 tons of weld iron, 82 tons of cast steel, and 200 tons of cast iron were employed. The rolled steel had a tensile strength of 28·2 tons per square inch, with an elongation of 24·3 per cent., while for the cast steel the tensile strength was 31·5 tons, with 7·85 per cent. elongation; for the weld iron, 23·6 tons and 13·8 per cent.; and for the rivet iron, 24·5 tons tensile strength and 26·1 per cent. elongation.

Further details as to the Alexander Bridge, Paris, and the steel construction materials used in it, are given by Frahm.* Details are also given as to the mechanical tests such materials were required to withstand, and a large number of the results of such tests are tabulated. The mode of erection of the bridge is also given.

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[*] *Journal für Gasbeleuchtung und Wasserversorgung; Stahl und Eisen*, vol. xx. p. 1025, with one illustration.

[†] *Osterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. pp. 333–336, with seven illustrations.

[‡] *Stahl und Eisen*, vol. xx. pp. 739–746, 788–796, 851–856, with 46 illustrations.

[§] *American Architect*, June 30, 1900.

[‖] *Stahl und Eisen*, vol. xix. pp. 1116–1119, with numerous illustrations.

The re-bridging of the Tugela by the Patent Shaft and Axle Company in an extremely short time is also referred to by Frahm.†

Armour.—An illustrated description of the manufacture of guns and armour at the Bethlehem Steel Works has been published.‡

A review of the progress in the manufacture in the different countries has been issued,§ and some notes on the development of armour for naval purposes have been published, ‖ the various forms and qualities of armour, and the cost at which it has been supplied at different periods being discussed.

A recently published memoir of H. A. Harvey by his sons ¶ traces his connection with the armour plate industry and with numerous other manufactures in which he was a fertile inventor. Some illustrations are given of the first plates tested, and an account is given of the process of face hardening and of its adoption in various countries.

Gun Manufacture.—E. Goffe ** gives some notes on the construction of "Long Cecil," a 4·1 breech-loading gun, in Kimberley during the siege, 1899–1900. The tube was bored from a billet of hammered mild steel 10½ inches in diameter and 10 feet long, intended for shafting, and was strengthened by shrunk-on rings made from bars of 6 by 2½ inch Low Moor iron.

J. Castner †† describes the methods in use in Krupp guns for fastening the breech. Such fastenings are in principle based on either the use of the wedge or of the screw. Numerous modifications of both are described and illustrated.

Mention is made ‡‡ of the various arsenals of China, and in particular of one which is at a distance of some 13 miles from Shanghai, at the town of Kiang-Nan, on the banks of the Wei-Lung. At this arsenal there are two open-hearth furnaces, a 2000-ton hydraulic press, large armour plate rolling-mills, and shops in which all kinds of weapons, from muskets to guns of the largest size, are manufactured. The steel is made from Chinese pig iron manufactured from Chinese ores. All guns up to those of 6-inch calibre may be made completely at the works, without having to obtain any portion from abroad. Ammunition is also made at this arsenal, the capacity being about 5 tons of finished products per day. This arsenal was erected as far back as 32 years ago, and since then has been continuously at work. In 1898 it employed 2500 workmen, all being Chinese. Two Englishmen are the only Europeans employed to manage the works. It is not impossible that other arsenals have been erected inland, and of which nothing is known.

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* *Stahl und Eisen*, vol. xx. pp. 892-899, 942-947.

† *Ibid.*, pp. 320-322, with one illustration.

‡ *Scientific American*, May 19, 1900.

§ *Engineering*, vol. lxix. pp. 435-438.

‖ *Iron and Coal Trades Review*, vol. lx. pp. 685-686.

¶ A copy of this work has been presented to the Institute Library.

** *Institution of Mechanical Engineers' Proceedings*, June 1900, pp. 359-374, with three plates.

†† *Stahl und Eisen*, vol. xx. pp. 570-582, 647-653, with 28 illustrations.

‡‡ *Frankfurter Zeitung; Stahl und Eisen*, vol. xx. pp. 864-865.

Shipbuilding.—The gradual evolution of the modern ironclad from the older types of battleships is described by Rudloff.*

Illustrations are published † of the Russian cruiser *Askold.* This vessel has 6000 tons displacement, a speed of 23 knots, and carries in her bunkers 1100 tons of coal.

Some of the larger steamers built in Germany in recent years are illustrated and compared by O. Flamm.‡

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* *Stahl und Eisen*, vol. xx. pp. 49–52, with eight illustrations.

† *Ibid.*, pp. 394–396, with two illustrations.

‡ *Ibid.*, vol. xix. pp. 1109–1115, with five illustrations.

PHYSICAL PROPERTIES.

Definitions of Pig Iron, Wrought Iron, and Steel.—A note by A. Pourcel * discusses the definitions of pig iron, wrought iron, and steel. Pig iron is the raw material from the blast-furnaces, and cannot be forged except in the form of malleable castings. Steel and wrought iron contain less carbon, and have a melting-point between 1200° and 1500° C. Differences in the carbon contents, in the power of hardening by quenching, in the method of manufacture by welding and fusion, and in the tensile strength, have been used alone or in combination as the basis of a definition. In practice the most usual mark of differentiation depends on the method of manufacture, wrought iron being considered as welded material and steel as cast metal.

The Crystallography of Iron.—A comprehensive treatise on the crystallography of iron has been written by F. Osmond.† Full accounts of the work of earlier observers are given, the references in each case being appended and their illustrations often being reproduced. The definition of a crystal and of the crystallised state is first discussed, and then follows an account of the facts which may serve in determining the crystallography of *gamma*-iron. These are classified in five groups:—(*a*) The existence of crystals formed during the solidification of the mass in the cavities of ingots or castings of steel and cast iron; (*b*) the structure of quenched steel; (*c*) the structure of manganese steel; (*d*) the structure of nickel steel; (*e*) the structure of iron and its alloys in the range of stability of *gamma*-iron, as revealed by etchings conducted at the proper temperature. The observations on steel and iron recorded under the first of these headings all tend to prove that *gamma*-iron crystallises in the cubic system, assuming preferably the shape of the octahedra, more or less distant from its perfect form, with probable octahedral or cubic cleavages. The four other sources of information referred to above give indications which are not conclusive as such, but which are concordant, or at any rate consistent, with the conclusions derived from the first source.

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* Paris Congress on Mining and Metallurgy.

† *Annales des Mines*, vol. xvii. pp. 110–165; translated in the *Metallographist*, vol. iii. pp. 181–219, 275–290.

The crystalline structure of metals is dealt with by J. A. Ewing[*] and W. Rosenhain. The investigations described deal principally with the phenomena of annealing.

The Microstructure of Iron.—G. Charpy[†] traces the recent advances in metallography, and refers to the use of alumina for polishing sections.

A. Sauveur[‡] reviews the progress of metallography in 1899, giving a summary of the work done in the year by various experimenters.

J. O. Arnold[§] discusses "The Internal Architecture of Steel," and explains the effect of various alloys on the structure and qualities of the metal. It is pointed out that mechanical tests are not sufficient to show whether changes in steel would or would not take place under long-continued vibration. For the purpose of discovering danger in this direction the microscope is the best guide. By means of micrographs illustrations are given of forms of structure which should be avoided, and their effect in producing rupture.

A. Sauveur[||] discusses the contention of K. Glinz,[¶] that coke and charcoal iron can be differentiated by their microstructure. Samples of coke iron cast in sand and in chill moulds show differences similar to those found by Glinz in the different kinds of iron, and this supports the statements made by E. Heyn,[**] that the structure is a function of the temperature and rate of cooling.

Some photomicrographs by F. C. Lau[††] show the structure of steel quenched from the melting-point. One specimen containing 2·40 per cent. of carbon shows cementite and martensite, the latter being most markedly developed. The other specimen, containing—

C.	W.	Cr.	Mn.	Si.	P.
2·29	5·63	0·53	1·87	0·50	0·04

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[*] *Proceedings of the Royal Society*, vol. lxvii. pp. 112–117.

[†] Paper read before the Paris International Congress on Applied Chemistry.

[‡] *The Mineral Industry*, vol. viii. pp. 702–714.

[§] Paper read before the British Association, 1900.

[||] *Metallographist*, vol. iii. pp. 154–156.

[¶] *Journal of the Iron and Steel Institute*, 1900, No. I. p. 399.

[**] *Stahl und Eisen*, vol. xx. p. 36.

[††] *Metallographist*, vol. iii. pp. 244–247.

shows a kind of pearlitic structure of rounded grains with intermediate white areas.

H. Le Chatelier has drawn up a report on the present state of knowledge concerning the allotropic modifications of iron and steel for presentation at the Paris International Congress on Applied Chemistry. The various points of transformation are described, and the microstructure of the metals is discussed.

Magnetic Properties of Iron and Steel.—L. M. Potts * has investigated Rowland's method for determining the loss due to hysteresis. Its advantage is that small samples may be used.

S. W. Richardson and L. Lownds † describe experiments that have been made to ascertain in what way the hysteresis loss between given limits of the field strength is connected with the temperature for an alloy containing 3·64 per cent. of aluminium. The experiments show that the hysteresis loss attains a maximum value at a temperature considerably higher than the temperature of maximum induction. The changes produced in the magnetic properties of the alloy by heating and subsequent cooling have also been investigated. The properties depend largely on the previous history of the specimen; but there does not appear to be any essential difference between the behaviour of the alloy during heating and cooling except near the temperature of maximum permeability. Experiments have also been conducted on the abrupt change in the permeability that takes place at a temperature of about 650° C. The conclusions arrived at are as follows:—(1) The hysteresis loss at first diminishes as the temperature rises; it then increases and reaches a maximum at about 550° C.; on further heating it falls off rapidly, and is negligible at 700° C. (2) The magnetic properties of the specimen depend largely on its previous history. (3) There is no essential difference between the behaviour during heating and cooling except near the temperature of minimum permeability. (4) An abrupt increase in the permeability takes place at about 650° C. during heating, followed by an equally abrupt diminution on further heating. (5) This abrupt change is more marked with falling than with rising temperatures. (6) Continued heating and cooling diminish the permeability. (7) The curve connecting temperature of minimum permeability and percentage of aluminium is a straight line. (8) The microscopic examination of the specimens shows the presence of crystals.

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* *American Journal of Science*, vol. x. pp. 91–114.

† *Engineering*, vol. lxix. p. 796.

From the ample materials supplied by Grösser, K. Schreber[*] has unravelled the following regularities in the complicated relations between magnetisation and torsion. Every iron or steel wire free from torsion acquires a permanent twist under magnetisation, which, with increasing field intensity, tends towards a maximum. The direction of the torsion is, strange to say, independent of the direction of magnetisation. In fact, it is reversed several times in the same wire as the field increases in strength. In iron the previous history of the wire does not seem to affect the amount of the twist, but in steel it does, to an extent which cannot as yet be stated in a simple manner. Moreover, the permanent twist is greater in steel than in iron. Besides the permanent twist, the wire experiences a temporary twist, which increases with the field as soon as the permanent twist has attained its maximum. Beyond that maximum, also, the temporary twist has always the same sign. An eye looking along the lines of force would always see the twist taking place in the direction of the hands of a watch. This practically diminishes the torsional elasticity in that direction. The observation recalls the phenomenon of the twisting of cathode rays in a magnetic field running along them.

An exhaustive investigation of the various conditions affecting the permanency and the moment of a steel magnet has been carried out by H. Frank.[†]

A. Gray[‡] and E. Taylor Jones have studied the change of resistance in soft iron wires by magnetisation.

R. L. Wills[§] has investigated the effect of heat on the magnetic properties of certain alloys of iron. The results confirm the impression as to the exceptional character of the influence of aluminium upon iron.

C. Maurain[‖] has studied the magnetic properties of iron in the act of deposition.

The Mechanical Properties of Steel.—Baron H. von Jüptner[¶] discusses the relations which exist between the mechanical properties and chemical composition of steel. He refers to communications made by himself in 1895 and 1896 to the effect that it was possible to deduce the mechanical properties of steel, as shown by the tensile test, from the chemical composition, formulæ given by him being employed for that purpose. These were based on the assumption that the influence which small quantities of impurities present exert on these properties of iron are alike for equal atomic quantities of all these substances, an assumption which finds an analogy in the behaviour of dilute solutions. The formulæ then proposed were based on carbon 12, silicon 28, and manganese 55, the latter value being rounded off to 56 for the simplification of the equation, when

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[*] *The Electrician*, October 26, 1900, p. 16.
[†] *Annalen der Physik*, 1900, No. II. p. 338.
[‡] *Proceedings of the Royal Society*, vol. lxvii. pp. 208–215.
[§] *Philosophical Magazine*, vol. l. pp. 1–36.
[‖] *Comptes Rendus de l'Académie des Sciences*, August 13, 1900.
[¶] *Stahl und Eisen*, vol. xx. pp. 939–941.

$\frac{1}{12}$ or $\frac{2}{3}$ part carbon,
$\frac{1}{28}$,, $\frac{2}{7}$,, silicon,
$\frac{1}{56}$,, $\frac{1}{7}$,, manganese,

gave similar effects.

Since, however, one and the same steel gives different results as to tenacity and reduction of area when subjected to different thermal and mechanical treatment, the equation had to be modified, and there is obtained for tensile strength—

$$\begin{aligned}\sigma_B &= A + \tfrac{20}{3}\,C + \tfrac{20}{7}\,Si + \tfrac{10}{7}\,Mn \\ &= A + \Sigma\end{aligned}$$

while for the reduction of area the formula is—

$$\begin{aligned}q &= B - 7\,\Sigma \\ &= B - (\tfrac{140}{3}\,C + \tfrac{20}{1}\,Si + \tfrac{10}{1}\,Mn)\end{aligned}$$

or, simplified—

$$\begin{aligned}q &= B - (47\,C + 20\,Si + 10\,Mn) \\ &= B - \Psi\end{aligned}$$

For one and the same locality and method of production the values of A and B remain fairly constant. For instance, in the case of Neuburg open-hearth steel in its natural unannealed condition, A averages about 2·50 tons and B = 60 per cent. The author shows by a number of testing results that those obtained in actual practice closely agree with those calculated by means of these formulæ; and he observes that he has heard that they are regularly and successfully employed in some German and French works, instead of actual testing. Amongst these are the Peine Ironworks, where a further modification of the formulæ has been made in order to take in phosphorus, its atomic weight for the sake of simplicity being considered as 32. The Peine tenacity formula is consequently—

$$\sigma_B = A + \tfrac{2}{30}\,C + \tfrac{2}{70}\,Si + \tfrac{1}{70}\,Mn + \tfrac{1}{40}\,P.$$

This agrees in practice remarkably closely with actual tests, as the author shows. The agreement is even closer than in the case of the Neuburg steels, which are of very varying degrees of hardness. The original hypothesis on which these formulæ are based, that an equal number of atoms in the case of small quantities of impurities alter the mechanical properties in an identical way, necessitates the modification that of course only an equal number of molecules can exert the same influence. If, then, this is true for an equal number of atoms, it can only be because the molecules of the active elements possess the same number of atoms. If one assumes that sulphur also behaves in the same way as regards the number of atoms in its action on the tensile strength, but reduces this, and calculates the value of Σ by the formula—

$$\Sigma = \tfrac{20}{3}\,\mathrm{C} + \tfrac{20}{7}\,\mathrm{Si} + \tfrac{10}{7}\,\mathrm{Mn} + \tfrac{10}{4}\,\mathrm{P} + \tfrac{10}{8}\,\mathrm{Cu} - \tfrac{10}{4}\,\mathrm{S},$$

one obtains values which closely correspond with the actual ones. It is evident, however, that the action of copper is not directly comparable to those of other elements, atom for atom, and the author suggests a modification of the formula for the purpose of meeting the case. Sulphur and oxygen reduce the tensile strength, and in the equation for Σ they must be represented by negative values. Unfortunately, in the case of oxygen no accurate data are available to determine this value with any degree of accuracy. Whether the same general law applies to these two as well as to the other elements is uncertain. The equation must be written, therefore—

$$\Sigma = \tfrac{20}{3}\,\mathrm{C} + \tfrac{20}{7}\,\mathrm{Si} + \tfrac{10}{7}\,\mathrm{Mn} + \tfrac{10}{7}\,\mathrm{P} - f(\mathrm{S}) - F(\mathrm{O}).$$

As previously mentioned, these empirical formulæ only agree for use in connection with one and the same mechanical and thermal treatment of the metal.

Influence of Low Temperature on Iron.—C. Schäfer,* in a paper read on June 15, 1900, before the German Physical Society, gave the results of experiments on the elasticity of metals at very low temperatures, a solid carbon-dioxide-ether mixture giving a temperature of −70° C., and liquid air one of about −180° C. The modulus of elasticity and of torsion were determined as well as their absolute values. These are given in the case of a number of metals, including iron and nickel.

The Strength of Ductile Materials under Combined Stresses.—J. J. Guest † throughout his experiments has used the

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* *Stahl und Eisen*, vol. xx. p. 1024.

† *Engineering*, vol. lxix. p. 734.

"yield point" of a material as the true criterion of its strength, and has rejected the elastic limit as being modified by local yielding. At present two theories are used in the calculation of strength of material.

The first is that the material yields when one of the principal stresses reaches a certain amount. This theory, which was adopted by Rankine and is used by engineers in England and America, is not in accord with recent experiments. The second theory is that the material yields when the greatest strain reaches a certain amount. This was advocated by St. Venant, and is used by engineers on the Continent. Besides these there is a third theory of elastic strength, in which the condition of yielding is the existence of a shearing stress of a specific amount. In the case of a solid bar subjected to torsion, there is a variation in the strain from the axis outwards, and consequently the materials have been used in the form of thin tubes. This allows the application of an internal fluid pressure. The specimens were of steel, copper, and brass, the state of set caused by drawing having been removed by annealing.

The tubes were subjected to (1) torque; (2) torque and tension; (3) tension only; (4) tension and internal pressure; (5) torsion and internal pressure; and (6) internal pressure only. The axial elongation, the twist, and occasionally the circumferential strain, were measured. Towards the end of the experiments observations were made on bending. The results disprove the maximum-stress theory, and are at variance with the maximum-strain theory.

The maximum shearing stress developed and the corresponding shearing strain were comparatively constant throughout the experiments, and no other simple relation between the stresses and strains was even approximately constant. The results of the experiments have been plotted synoptically on a curve, and the several lines have been drawn upon which these points should be according to the various theories. It is readily seen that the points cluster round the line which represents the existence of a specific shearing stress. The author therefore favours the existence of this stress for any material.

Influence of Hardening.—A paper was read by A. Carnot and Goutal* before the Academy of Sciences, in which they give the results of their investigations on the influence of hardening on the state of combination in steel of elements other than carbon. It has been shown that in slowly cooled steel the sulphur present combines with the manganese in preference to iron, since treatment with cupric potassium chloride solution leaves an insoluble residue of cupric sulphide containing sulphur equivalent to the manganese present, whereas iron sulphide is not attacked by the solvent in question. Precisely similar results are obtained with hardened steel, whence it follows that hardening has no influence on the condition in which sulphur exists in the metal. The same applies to phosphorus, present as iron phosphide, Fe_3P, which is left undissolved when the hardened or unhardened steel is treated with cupric potassium chloride solution. On the other hand, arsenic, which exists in the free state in unhardened steel, is found to be present mainly as an iron arsenide, Fe_2As, in the hardened metal, this arsenide being left undissolved by treatment with 7 per cent. sulphuric acid with exclusion of air. Copper is present chiefly in the uncombined state in both hardened and unhardened steel, as was shown microscopically after digestion with dilute acid or with a mixture of hydrogen peroxide and ammonium chloride solution. Nickel in hardened as in unhardened steel appears to exist in the metallic condition, either mixed with or dissolved in the iron.

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* *Comptes Rendus*, vol. cxxxi. pp. 92–96.

Nickel Steel.—A. Abraham[*] describes the nickel steel exhibit at the Paris Exhibition. As regards, in the first instance, nickel steel with less than 10 per cent. of nickel, it is pointed out that nickel steel with from 6 to 7 per cent. of nickel has long been known. Three varieties of steel correspond as regards their properties with ordinary carbon steels, except that when hardened at a cherry-red and annealed at a dark red they are less brittle, and when submitted to mechanical tests are subsequently found to possess a higher limit of elasticity. They are especially well suited for the manufacture of armour plate, and in America they have also been employed in large forgings. Tests are given of various examples of nickel steel of different percentages of nickel below 10 per cent., and some of the exhibits made of this material are also referred to.

The next kind of nickel steel dealt with is that containing from 12 to 13 per cent. of nickel. This metal is used for guns, and the results are given of the mechanical tests of such material used for the above purpose by Holtzer & Co. Axles are shown that have given good results in practice, both of steel with a percentage of nickel less than 10, and of one with 12 per cent. of nickel.

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[*] *Génie Civil*, vol. xxxvii. pp. 268–271; *Stahl und Eisen*, vol. xx. pp. 899–901.

The next class of nickel steels considered comprises those containing from 20 to 25 per cent. of nickel. Amongst the special nickel steels with more than 10 per cent. of nickel, only those with from 20 to 25 per cent. have found a real industrial application. The large French works make these steels regularly both in open-hearths and in crucibles, and work it up into sheets and plates. Tests of this kind of steel are given. Nickel steel with 25 per cent. of nickel is also used for boiler-tubes, wire, wire-rope, and springs, and the results are given of a number of other mechanical tests of these materials. In consequence of its high price, steel with 25 per cent. of nickel has only found a limited degree of application in practice.

A fourth kind of commercial nickel steel is that with more than 25 per cent. of nickel. Steel containing 36 per cent. of nickel is used with advantage for instruments of precision in the manufacture of watches, &c. Steel containing 44 per cent. of nickel is used in the form of wire in the manufacture of "wire glass" and as a substitute for the more expensive platinum wire in incandescent lamps. The results of mechanical tests of such steels are given. Both the hardened steels with 36 per cent. and with 44 per cent. of nickel showed a silky fracture when broken in the tensile test.

H. Souther * describes the properties and uses of nickel iron alloys, mainly confining himself to abstracts from the recent monographs of Hadfield and Browne.

Experiments by Rudeloff † comprised as a preliminary the examination of nine kinds of commercially pure nickel obtained from different works. These were analysed and subjected to mechanical and physical tests. The three best kinds were used in the subsequent experiments. In preparing the test-pieces, it was found that castings of pure nickel are not sound unless a magnesium addition has been made. From every fusion two ingots were cast, one of which remained as cast whilst the other was hammered out. These latter, without exception, showed cracks. The mechanical treatment did not change the conductivity for heat or for electricity in any marked degree. Nickel containing manganese was found as cast to possess a greater tensile strength and greater elongation than nickel free from manganese. Mechanical treatment increased both ultimate strength and

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* *The Mineral Industry*, vol. viii. pp. 438–449.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. p. 408.

elongation in each case, but more in that of the pure nickel than in the case of that containing manganese. It was, therefore, decided to use, when making the nickel-iron alloys, a material provided by Krupp of Essen. A series of alloys of iron and nickel were made in graphite crucibles provided with basic linings. The percentages of nickel were respectively 0·5, 1, 2, 3, 4, 5, 8, 16, 30, 60, and 95, while one sample free from nickel, and one consisting of nickel itself, free from iron, were also prepared. For alloys rich in iron it was found necessary, when casting, to add one part of aluminium per thousand parts of the alloy, and for alloys rich in nickel one part of magnesium per two thousand. The alloys containing 30 per cent. of nickel and upwards broke up under the hammer. The expansion caused by heat diminished as the percentage of nickel rose, until a minimum was reached at about 16 per cent. of nickel, but with 98 per cent. of nickel it was higher than in the case of the iron free from nickel.

The influence exerted by carbon was also examined into. The alloys, with up to 3 per cent. of nickel and their maximum carbon contents, were so hard before annealing that they could not be touched by tools. So, too, were the various alloys containing 8 per cent. of nickel and different quantities of carbon, with the exception of the one containing 0·1 per cent. of carbon. The addition of 3 per cent. of nickel causes the liberation of a good deal of the carbon in the form of graphite. With carbon in excess of 0·5, the alloy with 60 per cent. of nickel gave the worst results when submitted to mechanical tests, and that with 3 per cent. of nickel the best results. For lower percentages of carbon (0·3 to 0·5) the maximum tensile strength was found to be possessed by the alloy with 60 per cent. of nickel. The 3 per cent. alloy showed otherwise the best mechanical properties, while pure iron gave generally the lowest results in the mechanical tests.

L. Dumas * discusses allotropic transformations which occur in alloys of iron and nickel. The author, in the first place, refers to the experiments in this direction of Dewar and Fleming, and also of Osmond. Similar experiments made with alloys containing about 25 per cent. of nickel are now described by the author. The alloys dealt with contained from 16·01 per cent. to 29·94 per cent. of nickel, 0·079 to 0·640 per cent. of carbon, and 0·153 to 0·880 per cent. of manganese. The alloy with 16·05 per cent. of nickel also contained 3·02 per cent. of chromium; all the other alloys contained over 21 per

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* *Comptes Rendus des Séances de l'Académie des Sciences*, May 14, 1900.

cent. of nickel. The first set of alloys, containing up to 0·343 per cent. of carbon and 0·650 per cent. of manganese, resulted in showing that up to 25·84 per cent. of nickel the non-reversible points are above 0° C. From 27·12 per cent. of nickel the point of transformation on cooling is below 0° C., while at 29·94 per cent. of nickel even solid carbon dioxide does not produce the non-reversible point of transformation. This point, if it exists, which does not appear probable, would only show itself in liquid air. With 25·84 per cent. of nickel in the alloy there are two points of transformation existing simultaneously—one reversible and one non-reversible. As the percentage of nickel increases the reversible point rises and the non-reversible one is lowered.

The points of transformation are as follows in the alloys shown:—

Composition.			Points of Transformation.	
Nickel.	Carbon.	Manganese.	Reversible.	Non-reversible.
Per Cent.	Per Cent.	Per Cent.	°C.	°C.
25·27	0·587	0·880	+75	none at −78
24·61	0·640	0·880	about −25	none at −188
21·90	0·570	0·480	about −25	none at −78
16·05	0·535	0·828	none at −188	

The reversible transformation-point of these alloys shows itself on cooling by the appearance of extremely feeble magnetism, which increases in intensity as the temperature falls. The three first became distinctly magnetic in solid carbon dioxide. The second was immersed in liquid air, and its magnetic character had still further increased. The addition of carbon here brought out in these specimens their reversible transformation, which is lowered as the percentage of nickel is diminished. None of the alloys of iron and nickel appear to be eutectic in character. Nickel lowers the points of transformation of iron, and iron those of nickel, although it commences by increasing them. The result is that the magnetism of alloys which have not been submitted to the influence of temperature below 0° C. is due exclusively to iron if the percentage of nickel is below 25, and exclusively to nickel if the nickel contents is above 26 per cent. Between 25 and 26 per cent. of nickel the magnetism has disappeared almost entirely at the ordinary temperature, in consequence of the simultaneous depression of the transformation-points of iron and nickel. It may be added that the points of transformation referred to are magnetic ones.

The announcement of the high thermo-electric force of nickel steel containing 28 per cent. of nickel having given rise to some doubts, C. E. Guillaume* forwarded an authentic sample of such steel to E. Steinmann for re-determination. The latter announces now that the phenomenally high value of −2·461 microvolts with reference to lead is not shown by the authentic specimen, which only shows 385 microvolts. The old specimen turns out to have been wrongly labelled. It should have been marked as containing 36·1 per cent. of nickel.

The Influence of Copper on Iron.—W. Lipin,† after referring to the investigations of A. L. Colby, observes that in 1895 he himself published the results of a somewhat similar investigation made at the Putilov Works at St. Petersburg. He did not, however, confine his investigations to steel or to a copper contents of 0·6 per cent., as in Colby's experiments, but examined also into the question as to the influence exerted by copper on pig iron and puddled iron, and to copper percentages which considerably exceeded that above mentioned. These were published at the time in *Gorny Journal*, No. 8, and to them he now again refers. After referring to older investigations as to the quantities of copper that can be taken up by pig iron, the author adds that in his experiments up to 7 per cent. of copper was taken up by the iron used. Pig irons were selected that were not too high in silicon or other impurities, those chosen being Swedish charcoal irons containing :—

	Per Cent.
Total carbon	3·00 to 3·55
Graphite	2·70 ,, 2·95
Silicon	1·25 ,, 1·60
Manganese	0·60 ,, 0·80
Phosphorus	0·075 ,, 0·095
Sulphur	0·010 ,, 0·020

The pig iron was melted down with copper in graphite crucibles, about 30 lbs. of pig iron being used in each test. The percentage of copper subsequently found by analysis was always slightly greater than that actually added, thus showing that there was practically no loss of the copper, the oxidation being confined to the pig iron. The experiments showed that as the percentage of copper in the pig iron increased, so did its relative fluidity at any given temperature. The fracture became more and more coarsely crystalline and brighter as the copper percentage rose. In tabular form are shown the results of the chemical analysis and of the mechanical test in the case of fifteen tests. The addition of copper raised the tensile strength, sometimes a little, and sometimes considerably. Thus, while the original cast iron had a tensile strength of 19 tons per square inch, the sample containing 4·9 per cent. of copper had a tensile strength of 22·2 tons per square inch. Copper was not found to produce any marked chilling effect. Even 4·9 per cent. of copper left this Swedish pig iron still a "grey" iron when cast, whereas 1·5 per cent. of manganese or 2 per cent. of chromium chilled it completely. The maximum percentage of copper that pig iron will take up completely was found to be 5, both for grey and white irons. The copper makes the pig iron more fluid when molten, and denser when cast, while it tends to increase its strength. Its influence is, however, not very marked, and is at least far less than that of other elements. It does not seem probable that any advantage to foundry practice is to be expected from the use of copper, but, on the other hand, its presence in the minerals to be used in the manufacture of foundry pig iron need not give rise to any apprehension. It is absolutely unnecessary to separate, that is, any oxidised copper ore that may be present.

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* *Comptes Rendus*, July 2, 1900; *Electrician*, vol. xlv. p. 485.

† *Stahl und Eisen*, vol. xx. pp. 536–541, 583–590.

The author next deals with the influence exerted by copper on malleable iron and steel. It was formerly believed, he observes, that even very small quantities of copper made steel red-short, but the results obtained by various experimenters differed widely from each other, as the author shows. The experiments made at the Russian ironworks under the author's direction showed that iron containing up to 3 per cent. of copper could be readily worked. When containing a considerable percentage of copper the metal was fairly elastic, and when subjected to malleable action behaved like steel rather than iron. Cracks, however, began to show themselves under such treatment. When the percentage of copper reached 4·7, and when the percentage of copper was from 7 to 10, the cracks became so bad that the metal even fell entirely to pieces. Results are given of the mechanical tests of the various samples. The tensile strength and limit of elasticity increased with the rise of the percentage of copper up to 3·20, but somewhat irregularly. There were, however, slight differences in the percentages of the other constituents also present. The original iron had the following percentage composition:—

C.	Si.	Mn.	P.	S.	Cu.
0·10	0·09	0·14	0·028	0·034	0·0

This metal had a tensile strength of 26 tons per square inch, and an elongation of 27·8 per cent., while the metal having a composition—

C.	Si.	Mn.	P.	S.	Cu.
0·13	0·14	0·30	0·023	0·009	3·20

had a tensile strength of 46·5 tons per square inch and an elongation of about 13·3 per cent. Its limit of elasticity was at 38·7 tons per square inch. In the case of ingot iron such as that mentioned above, and containing from 0·07 to 0·15 per cent. of carbon and only a little sulphur, red-shortness did not become evident when there was less than 3 per cent. of copper present. With this or a slightly higher percentage the metal shows signs of cracking on rolling. Experiments showed that a strong but careful heating and annealing exerts an excellent effect on such cupriferous material. Hardening in oil exerts a greater influence on cupriferous iron than it does on iron free from copper, and while increasing the ultimate tensile strength only very slightly, diminishes the elasticity. Hardening in water has a similar, but of course more energetic action. Hardening and subsequent annealing does not markedly improve the qualities of cupriferous material, but the experiments also showed that the cupriferous metal with low percentages of copper was quite as good generally as metal entirely free from copper. The results of a large number of mechanical tests are given in proof of these statements. These are accompanied by analyses.

Other series of tests were made with a steel containing—

C.	Si.	Mn.	P.	S.	Cu.
0·42	0·09	0·20	0·035	...	0·00

To this copper was added in varying quantities. Analyses are given of the products with up to 4·12 per cent. of copper; the percentages of sulphur shown in the two cases in which it is given are 0·031 and 0·034. The steel rolled quite well as long as the percentage of copper did not exceed 2; above 2 per cent. red-shortness became observable. When the percentage of copper reached 2, water-hardening became so energetic that the metal subsequently showed no elongation whatever. Long and careful annealing greatly improved the quality of the steel—so much so, indeed, that the elongation shown on testing was subsequently as much as 20 per cent. in the case of a steel that contained 3 per cent. of copper. Steel containing 0·5 per cent. of carbon and more than 1 per cent of copper is suitable for tools.

A further series of experiments was made with steel containing—

Carbon.	Silicon.	Manganese.	Phosphorus.	Sulphur.
0·98 to 1·0	0·20 to 0·25	0·15 to 0·20	0·02 to 0·03	0·008

The percentage of copper varied between 0 and 3. Hardening could be done in oil but not in water, but even oil hardened so energetically that the metal became very brittle and crushed in the jaws of the testing machine. The tests made showed that the presence of copper in steel, such as the above, greatly increases this hardening power, but if the metal is annealed at a high temperature and for a long time, the influence of the copper ceases almost entirely to be observable.

Other tests referred to cupriferous weld iron and to the puddling of cupriferous pig iron, and these showed that the copper did not possess any deleterious action on the metal.

A. Ruhfus,* in discussing Lipin's investigation on the influence of copper on steel, points out that the conclusions deduced will be considered by many to be decidedly at variance with their experience in practice; for instance, the statement that red-shortness is not brought about by copper in iron and steel unless there is over 2 or even 3 per cent. of copper present. This conclusion the author considers to be far too general, and not to hold good for ingot iron. His own experience shows that the maximum permissible percentage of copper in ingot iron, which may be present without causing the metal to show signs of red-shortness on rolling, is 0·4, or for steel containing more carbon and manganese 0·5, assuming that phosphorus and sulphur do not exceed 0·05 per cent. If the metal is to be subjected to a welding process the maximum percentage must not exceed 0·3 for ingot iron or 0·4 for steel. Red-shortness is more evident in the heavier ingots from one and the same charge than in the ingots of smaller size, probably due to the fact that liquation phenomena are more likely to take place in the larger ingots than in the more rapidly cooled ingots of smaller size.

The author considers that there are various causes which may explain the difference between the results of Lipin's experiments and those which are observed in practice. Not the least of these lies in the fact that Lipin's experiments were made in crucibles, and under conditions which largely exclude oxidation, the copper being added in the metallic form. Now it is by no means certain that in blast-furnace metal the copper is all present as such, or whether it may not be also in some other form, combined, that is, with oxygen or some other element. Thus the metal from various charges from an open-hearth, to which 0·4 per cent. of metallic copper had been added to raise the copper in the iron to 0·55 per cent., rolled very much better than similar charges whose percentage of copper, due only to the copper in the pig iron used, was but 0·3.

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* *Stahl und Eisen*, vol. xx. pp. 691–692.

Testing Metals.—J. Gilchrist [*] discusses Wöhler's theories on the strength of materials exposed to repeated stresses, and is of the opinion that the average stress in the bars broken in Wöhler's machines did not reach the statical breaking load, but the fracture began at some imperfection, and a uniform bar would bear an indefinite number of repetitions both in tension and compression beyond the elastic limit.

At the Paris International Congress on Mining and Metallurgy, Hartmann gave an account of his investigations on the phenomena which accompany the permanent deformation of metal. One or two sets of striations or markings which follow straight or spiral paths and cross each other are developed when metal is strained beyond the elastic limit. The forms that these take under varied circumstances are described.

W. Minty [†] gives some diagrams to show the effect of manganese, carbon, and phosphorus on the tensile strength of steel as calculated from a large number of tensile tests. A base strength of 34,600 lbs. is taken, and to it are added amounts depending on the percentages of the various elements present. The method does not seem to be applicable to the elastic limit.

At the meeting of the Congress on Testing Materials at Paris, A. L. Colby gave a review of the American standard specifications, test pieces, and methods of testing iron and steel adopted by Committee No. 1 of the American Section of the International Association for testing materials, with a discussion of the commercial methods for the physical and chemical testing of iron and steel in use in the United States. The statements made are based on replies from thirty-three of the leading steel producers in that country. The author contributes a paper to the present volume covering the ground in this paper.

L. Moya [‡] describes the Spanish Government laboratory for testing materials.

Basic Bessemer Metal for Bridge Construction.—A committee having been appointed by the Austrian Association of Engineers and Architects in 1895 to investigate the suitability of basic Bessemer metal for bridge construction purposes, experiments have been made on an extensive scale, the conclusions drawn from which are given in a report which is signed by J. E. Brik, the chairman, and the sixteen members of the committee.* The committee found the soft metal examined by them to give good results when used for beams, but beams made of harder metal were much less satisfactory. The harder varieties of basic Bessemer ingot metal suffer badly when rivet holes are punched through them, and basic Bessemer metal cannot be considered satisfactory for bridge construction purposes if it has a tensile strength exceeding 4·3 tons per square centimetre. A basic Bessemer iron to be used for such purposes should have a tensile strength lying between the above as a maximum limit and 3·5 tons per square centimetre as a minimum. The rivet holes should be drilled and not punched, and on no account must the metal be subjected to mechanical treatment at a yellow or blue heat. A red heat must always be employed. Other suggestions are also made. The material to be used for rivets should have a good elongation, and a tensile strength varying from about 3·5 to 4 tons per square centimetre. The rivets must not be heated above a bright cherry-red. The riveting should as far as possible be done by machine. Hand-riveting must be performed as quickly as possible, care being taken to avoid injuring the surface of the metal. Two beams made of soft metal were found to possess in the one case the same strength as the original metal possessed, and in the other 93 per cent. of this, while two beams made of harder metal broke when the stress was only 82 per cent. of what the original metal would have withstood. The hard metal is subject to surface injury, and also liable to internal strains.

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[*] *Engineer*, vol. xc. pp. 203-204.
[†] *Engineering*, vol. lxx. p. 235.
[‡] *Revista de Obras Publicas*, 1900, p. 73.

Mehrtens † points out that the quantity of basic steel produced in the world in 1899 was about 10,500,000 tons, of which Germany alone produced 5,400,000 tons, or more than one-half. Comparing Austria-Hungary with Germany, it is seen that the latter produces nearly 6·5 times as much as the former. Curiously enough, however, while Germany produces 3,800,000 tons of basic Bessemer metal and only 1,600,000 tons of basic open-hearth metal, in Austria 600,000 tons is made of the latter and only 250,000 of the former. The basic Bessemer process was introduced into Austria in 1879, and the basic open-hearth process only in 1886, but by 1890 it occupied the foremost position, and the author gives comparative statistics showing the rise of the basic processes in Austria. The reason why the basic open-hearth process has advanced more rapidly than the basic Bessemer process lies mainly in the ore conditions, although in the early days the basic Bessemer metal was under a cloud which seems to have retarded its progress. The process could really only attain a truly flourishing condition in Bohemia, where the pig iron made contains an adequate percentage of phosphorus. In Moravia the ores are not rich enough in that element. The author quotes other statistics showing the progress made in the manufacture of basic steel in Austria in recent years, and then passes to a consideration of a report of the committee of the Austrian Association of Engineers and Architects.

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* *Beilage zur Zeitschrift des Oesterreichischen Ingenieur und Architektenvereines*, 1900, No. 17.

† *Zeitschrift des Vereines deutscher Ingenieure*, vol. xxxiv. pp. 880–882.

Steel Rails.—The report of the Committee appointed by the Board of Trade to inquire into the loss of strength in steel rails through use on railways have issued their report. The Committee, in the first instance, addressed a communication to the principal railway companies, asking them to assist the Committee by supplying the results of any experiments made on worn or broken rails, and by furnishing specimens of iron and broken rails, should the Committee decide to carry out any experiments.

The question of the loss of strength in steel rails is one which has excited much attention abroad. In Austria-Hungary and also in Germany "trial stretches" (*Versuch-strecken*) have been established on the lines of companies belonging to the Association of German Railway Boards, to which all railway companies in those two countries, and some in Holland and Belgium, belong. On each of these trial stretches rails from one cast of steel, of which the chemical composition and physical qualities have been ascertained, are laid, and are carefully observed. These stretches were established in 1891, but so far the time has not been sufficient to enable the Association to draw practical conclusions from the result of the observations. In Austria-Hungary, on the State railways, a regulation has been made requiring the renewal of rails when through wear they have suffered a diminution in height of 0·24 inch, the ordinary height of a rail on these railways being 5 inches, but in Germany no precise limit has been fixed. Two reports, dealing mainly with the effects of corrosion, were received from the Italian Government, and further information was received from the Belgian, Russian, and United States Governments.

The Committee decided to undertake a series of experiments on worn and broken rails, of which a number should be subjected to the ordinary falling-weight tests, and selected specimens to tensile and bending tests, the latter being also chemically analysed and examined by the recent methods of photomicrography. A considerable number of rails were tested in the presence of members of the Committee at the North-Eastern Railway Company's works at Gateshead, and at the Lancashire and Yorkshire Railway Company's works at Castleton, near Rochdale, and from them a selection of sixteen rails for further investigation was made by W. C. Unwin and E. Windsor Richards. The Lancashire and Yorkshire and North-Eastern Railway Companies supplied specimens of the chosen rails cut in a suitable manner for the further investigations proposed, which were apportioned amongst members of Committee as follows:—Mechanical tests, W. C. Unwin; chemical analysis, T. E. Thorpe; photomicrographic examination, Sir W. Roberts-Austen; atmospheric corrosion tests, W. R. Dunstan. W. C. Unwin gives the result of transverse, hardness, and tension tests on each of the selected rails, and also Tetmajer's and Dormus's coefficients of quality for each rail. T. E. Thorpe gives an analysis of each of the sixteen selected rails, and also of the rail, the fracture of which on the Great Northern Railway at St. Neots in December 1895 led to the appointment of the Committee, together with a summary of the methods employed in his analysis. Sir William Roberts-Austen describes the method of examining the rails by photomicrography, the effect of the various constituent elements, and the manner in which they may combine; he also compares the mechanical, chemical, and photomicrographic results of the experiments on the selected rails. His examination of the St. Neots rail disclosed the presence of patches of martensite in portions of the rail, and in order to ascertain whether this, the characteristic constituent of hardened steel, can be produced by other means than by quenching the steel from a high temperature, Sir William Roberts-Austen has examined a portion of the tube of a 4·7-in. quick-firing gun, making a study of the nature of the change produced by the action of the explosive. He is satisfied that the conditions which prevail in the gun do produce changes in the steel which resemble the local changes in structure of the St. Neots rail, but do not enable the local patches of martensite occurring in this rail to be attributed to any other known cause than the quenching of the steel from a high temperature. The structure of this rail is evidently abnormal. W. E. Dunstan gives an account of the manner in which atmospheric corrosion affects steel, having regard to its chemical composition and the nature of its structure. The results of his experiments are illustrated by selected photographs of the specially corroded surfaces of certain of the rails chosen by the Committee. These results show how important it is that the condition and mode of distribution of the constituents of steel, and not merely their nature and quantity as determined by chemical analysis, should be taken into account in judging of the suitability of the metal for the manufacture of rails. Local atmospheric corrosion is often determined by the presence of patches of irregularly distributed impurity. E. Windsor Richards, in addition to preparing an account of the falling weight tests, has drawn certain deductions from them, and in his conclusions refers to the effects on rails of incipient small cracks forming "nicks." E. P. Martin has conducted some experiments on rails in which fissures or nicks have been purposely made by a cutting tool. In addition to these experiments conducted by the Committee, Sir Lowthian Bell has tested a very large number of rails, and he has favoured the Committee with a memorandum thereon, in which he calls attention to the small proportion of rails broken annually, which he estimates as only one to every 25,000 laid down, and he also discusses the effect on a rail of the rolling weight of a train, and gives the vertical and lateral deflections due to the passage of a train at different rates of speed.

The Committee requested the chemical and engineering members to prepare criticisms on the evidence in the possession of the Committee from the chemical and mechanical points of view respectively. Sir William Roberts-Austen and T. E. Thorpe accordingly prepared a memorandum on the chemical aspect of the evidence before the Committee, and their own experimental work. In this memorandum they came to the following conclusions:—(*a*) The evidence before the Committee indicates what the limiting proportions of carbon, sulphur, phosphorus, manganese, and silicon should be. As regards the influence of phosphorus, it is pointed out that, in a broad sense, brittleness of steel does not depend on the total amount of phosphorus present, as that element may exist in steel in at least two different forms, one of which is comparatively innocuous. (*b*) It is very important that all who are responsible for the manufacture or use of steel rails should realise that steel is not the homogeneous mass it is often supposed to be, but possesses a complex structure. The nature of this structure will vary greatly with the mechanical and thermal treatment to which the metal has been subjected. The durability of the rail depends in no small measure on its structure, which may, if the specimens of steel have been suitably prepared, be revealed by the microscope. The peculiar structure of the St. Neots rail, for instance, can be exactly imitated.

W. C. Unwin, with the assistance of Sir Benjamin Baker and W. Kennedy, prepared a memorandum reviewing from the mechanical point of view the information before the Committee. In this memorandum the following conclusions are arrived at:—(*a*) The preponderance of fractures near the ends of rails seems to show that the greater straining action due to discontinuity at the joint is a contributing cause of fracture, and this can be remedied by adopting rails of sufficient strength with webs of ample thickness and secure types of fastening, and by care that no looseness arises in service. The fact that worn rails are improved in strength and ductility by annealing proves that part of the deterioration of rails in service is of the nature of what is sometimes termed "fatigue." It appears certain that in some cases fractures of rails have been due to fissures formed during service. How far the minute transverse fissures, very often noticed in the running surface of old rails, give rise to these larger induced flaws requires further investigation. It is not likely that they usually spread into the substance of the rail, because they are common in old rails, and fractures would be more frequent than they are if that were the case. Also, the evidence as to the existence of visible flaws or defects in the fractured surface of rails is very conflicting. In some cases, undoubtedly, the combined effects of the weakening of a rail by wear and corrosion, possibly also increased straining action from defective packing of sleepers, and the presence of a flaw or fissure of not inconsiderable size have led to fracture of the rail. That such defects appear most commonly in the head of the rail is evidence to a certain extent that they are induced by the hammer-hardening of the top surface; (*d*) it is very desirable that the mechanical tests to which rails are subjected should be as far as possible standardised in connection with (1) the weight, (2) the section, and (3) the chemical composition of the rail.

With these conclusions the Committee agree, and as regards chemical composition they do not think it desirable to insist upon too high a proportion of carbon, manganese, or silicon in the steel, having regard to the ordinary contingencies of manufacture, and the greater susceptibility of high carbon steel to thermal influences.

At the International Railway Congress, held at Paris in 1900, the question of specifications for railway rails was dealt with at considerable length by Bricka as regards Continental practice, by P. H. Dudley as regards American practice, and Poulet dealt with the practice in Great Britain and her colonies. The physical and chemical tests prescribed or adopted, and the methods of manufacture, treatment, and use were fully gone into.

R. W. Hunt,* after an historical account of the manufacture of rails in America, calls attention to the large production of the present time, one mill alone having turned out as much as 58,103 tons in a month. This faster work had somewhat altered the character of the steel in rails, but other considerations had not been neglected, and the outward character and finish had been improved to a radical extent. It is considered that the American makers were at the present time turning out not only the most rails, but also the best finished ones now produced. Another point to which attention was drawn was the standardisation of rail specifications in America. At one time almost every railway had its own particular section; the variations were slight, but sufficient to require the use of special rolls in their manufacture. Holley, in 1881, obtained from the eleven Bessemer mills then making rails in the United States drawings of 188 patterns considered standard ones, while 199 patterns of twenty-seven different weights per yard were regularly manufactured. The American Society of Civil Engineers appointed a Committee to consider the question of standard rail sections. This reported in 1893, and it was gratifying that in 1899 quite 75 per cent. of all the rails rolled by American rail mills were of what were commercially known as the American Society Sections. Heavier equipments and higher speeds required more rigid road beds, which could only be obtained by rails of heavier section. As to the amount of service yielded, the results were disappointing, and it was to be doubted whether such satisfactory ones would ever be obtained as were yielded by the lighter sections. The author next referred to the satisfactory wearing powers exhibited by rails renewed by the M'Kenna process, by which rails that had become unfit for further service in main line tracks were heated to a temperature of not more than 1500° F., passed through forming rolls, sawn hot, and cold-straightened. This treatment was no longer an experiment, for nearly 100,000 tons were in use, and so satisfactory did they promise to be as regards wear, that one chief engineer, on whose road many were in use, said, "No rail ought to be used at all until it has been renewed." As a steel rail maker, and an observer of the wear of rails of many sections and diverse chemical composition, he was led to advocate—(1) that work after careful heating of the steel should be continued until the temperature had been much reduced; and (2) that the carbon percentages should be increased in proportion to the increase of rail section, the ultimate amount being of necessity limited by the contained percentage of phosphorus.

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* *American Society of Civil Engineers, Proceedings*, vol. xxvi. pp. 752–767.

A. L. Colby* reviews the requirements of rail specifications as compared with those proposed for the standard American specifications proposed at the International Congress of the Association for Testing Materials. In forty-one instances the material is specified in eight cases, the carbon in 63 per cent., phosphorus and sulphur in 32 per cent., and silicon and manganese in about half. All prescribe a drop test, and 70 per cent. give a dead weight test. Finish, inspection, and other matters are also referred to.

In continuation† of the discussion W. R. Webster refers to the carbon limits and the finishing temperature; and Sir Lowthian Bell gives the results of a number of drop tests on steel rails made from the top, middle, and bottom of ingots, together with full analysis. The fractures took place at an average fall of 48·9 feet for tops, 64·5 feet for middles, and 77 feet for the bottoms; but the analysis showed only very slight average differences.

Some notes have been given ‡ on the life of steel rails. In the case of tramways so much depends on the endurance of the paving, and the various kinds are therefore considered in some detail. Railway rails are also considered. It is pointed out that in the case of railways the chief limiting consideration which determines the amount of work that can be obtained from steel rails, or their life, is the thickness of metal that can be worn off the face of such rail with a due consideration to safety; while in the case of tramways or street railways, in which the vehicular traffic runs on the same level as the track, it does not depend so much upon the amount of wear to the rail itself, as on the length of time the street paving on which these rails are laid lasts.

Sections of the rails and their fastenings, as used on the Manchurian railway built under Russian auspices, are given,§ together with the specifications for them, and also for the wheels and couplings.

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* *American Society of Civil Engineers, Proceedings*, vol. xxvi. pp. 768–773.

† *Ibid.*, pp. 940–948.

‡ *Engineer*, vol. xc. p. 77.

§ *Iron and Coal Trades Review*, vol. lxi. pp. 73–74.

The standards of track construction on more than fifty railways in the United States, Canada, and Mexico are given in tabular form. Dimensions, weights, &c., of the rails, spikes, joints, sleepers, chairs, frogs, and switches are included.*

Discussing the question † whether the tests now customary on the purchase of steel rails are really adequate, A. Martens ‡ refers to D. Miller's experiments. These showed that from the results of the tensile tests made there were no particular deductions to be drawn, but the bending limit must be as high as possible in good rails. Martens points out, however, that the tensile test offers important information as to the properties of the metal if properly performed. These are of little value if only round test-pieces are used, and these, too, are taken from the rail centre. A flat bar taken from the running surface of the rail would give far more useful results. Martens thinks that the most satisfactory tests for a rail are to submit it to the falling weight and bending tests, to test, that is, the whole piece of material in the form in which it would pass into actual use in practice. In the etching tests he considers that hydrochloric acid is not nearly so good as a solution of one part of copper ammonium chloride in ten parts of water. The section should be cleaned from grease by the use of alcohol and ether, and then plunged slantingly into the etching solution for one to five minutes. One minute is usually enough. The tests criticised led the author to consider that the only real point of importance to obtain a satisfactory rail, whether of soft or hard metal, was that it should be made of dense compact metal, free, that is, from porosity. The subject generally is dealt with in much detail, and it is suggested that (1) one rail of every charge should be broken; (2) that a falling weight test of some 10,849 foot-pounds should precede the bending test; and (3) that a rail should stand at least 64,000 lbs. per square inch before flaw sets in. The question of bending is dealt with in more detail, suggestions being made as to how it should be performed, the method advocated enabling a considerable saving in time to be effected.

Wheels.—In some notes § on wheels for railway rolling stock, chilled cast wheels and built up wheels are compared, and some particulars of tests adopted by the Austrian, Belgian, and German State railways for cast wheels are given. The thermal test of the Pennsylvania Railroad is also given, and in connection with this a paper by G. R. Henderson * is referred to, as advocating a certain percentage of manganese to enable the wheels to endure the test. In America the master car-builders' regular guarantee is for forty-eight months, and all wheels which run over five years may be considered as giving good service. As a result of a study of the analyses of such wheels, below are given what are considered to be the desirable limits for the chemical constituents of wheels:—

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* *Engineering News*, vol. xliv. pp. 142–147.

† *Journal of the Iron and Steel Institute*, 1900, No. I. p. 418.

‡ *Stahl und Eisen*, vol. xx. pp. 302–310, 369–377; with a sheet of illustrations and others in text.

§ *Iron and Coal Trades Review*, vol. lx. pp. 835–836.

	Per Cent.
Graphite	2·75 to 3·00
Combined carbon	0·50 ,, 0·75
Silicon	0·50 ,, 0·70
Manganese	0·30 ,, 0·50
Sulphur	0·05 ,, 0·07
Phosphorus	0·35 ,, 0·45

By comparing the above with the analyses of a large number of wheels it was found that these limits excluded those which broke through the rim in ten minutes or less under the thermal test; broke with twenty blows or less under the drop test; or gave less than two years' service. In analyses of seven wheels, which had given from eight to eleven years' service, the following were the limits:—

	Per Cent.
Graphite	2·56 to 3·10
Combined carbon	0·63 ,, 1·01
Silicon	0·58 ,, 0·68
Manganese	0·15 ,, 0·27
Sulphur	0·05 ,, 0·08
Phosphorus	0·25 ,, 0·45

Tests of Armour Plates.—Illustrations are given † of one of two armour plates made by a special process at the Manchester Works at Oppenshaw, and tested at Whale Island, July 3, 1900. It endured five blows from 100-lb. Holtzer projectiles, with striking velocities of 1970 to 2047 foot-seconds, and striking energies of 2691 to 2841 foot-tons. All the projectiles were broken up. The deepest penetration was 2¾ inches and surface scaling only was produced. The plate was 8 by 6 feet and 6 inches in thickness.

Particulars have appeared ‡ of some plates made at Terni, and tested at Muggiano near Spezia. One plate, tested on May 3, 1899, was 7 feet 10½ inches by 5 feet 3 inches and 5·9 inches in thickness. It endured six blows from a 6-inch projectile, weighing 99·6 lbs., of which the striking velocities were 1936 foot-seconds for the first five and 2313 foot-seconds for the sixth. All shots broke up, leaving their points lodged, but only the last shot penetrated, so that the point entered the backings. The plate was not cracked.

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* *Transactions of American Society of Mechanical Engineers*, vol. xx. pp. 615–628.

† *Engineer*, vol. xc. p. 335.

‡ *Ibid.*, p. 7.

A Krupp non-cemented plate 5 feet square by 4 inches in thickness made by Messrs. Cammell was tested at Netley, on February 2, 1900, and illustrations are given * of the tested plate. Three 5-inch Palliser shots were used, the first with a striking velocity of 1406 foot-seconds and 685 foot-tons energy, the second and third of 1750 foot-seconds and 1061 foot-tons. Four shots were then fired with 4·7 inch armour-piercing projectiles, at velocities ranging from 1720 to 1813 foot-seconds and energies from 923 to 1026 foot-tons.

After the war with China, Japan, as is known, commenced the construction of an important navy, building five large battleships, two of which are amongst the largest in the world. In addition six armoured cruisers, each of about 9700 tons, were also arranged for. All the battleships have been completed or launched, together with several of the cruisers. These armoured cruisers have both a large armament and also important armour protection. The *Yakumo*, one of these cruisers, built last year, has an armour belt from stem to stern, varying in thickness from 3·5 to 7 inches. The armour plates for this cruiser weigh 2100 tons. Illustrations are shown of two such plates after being subjected to firing tests, which they withstood very satisfactorily. They were not penetrated or cracked though fired at by heavy artillery. The plates are of hardened nickel steel.†

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* *Engineer*, vol. xc. p. 117.

† *Stahl und Eisen*, vol. xix. pp. 1102–1106, with six illustrations.

CHEMICAL PROPERTIES.

The Influence of Hydrogen on Iron.—E. Heyn * observes that the experiments of Müller and of Stead showed that when holes are drilled in steel ingots gas is evolved, and that this consists chiefly of hydrogen. As this is not the gas that would have seemed likely to have been present, it would appear that some affinity must exist between iron and hydrogen to cause this selection of the latter gas by the iron. The behaviour, too, of solid iron towards hydrogen points in the same direction. Although most of the hydrogen is given up by ingot metal just before it solidifies, yet some will be found in every ingot iron even after annealing and rolling. The cooling curve of electro-deposited iron given by Roberts-Austen forms a further marked advance in our knowledge of this subject. This metal had the hardness of fluor spar, and at 70° evolved considerable quantities of hydrogen. Further quantities were given off at higher temperatures *in vacuo*, and never entirely ceased, though after a temperature of 1300° C. had been exceeded it was but very small in quantity. After dealing with this at further length, the author describes experiments made at Charlottenburg with various kinds of iron which were heated in an atmosphere of hydrogen. One of these, No. I., was soft basic open-hearth rolled metal of the composition :—

C.	Si.	Mn.	P.	S.	Cu.
0·05	under 0·01	0·37	0·069	0·046	0·03

Another (II.) was a basic Bessemer beam metal of unknown composition; a third sample (III.) was a soft wire of ingot iron extremely low in carbon, and a fourth (IV.) was a hard ingot metal wire containing 0·37 per cent. of carbon. Nos. III. and IV. were of Westphalian origin. The experiments are described. They showed that if ingot iron is heated in hydrogen at temperatures between 730° and 1000°, and then hardened, the metal is much harder than it would have been had it been previously heated in air instead of in hydrogen. Slow cooling in hydrogen, as well as hardening after heating in this gas to temperatures below 730° seemed to be quite without action. Care has to be taken therefore in bending tests not to heat iron where it can come in contact with unburnt illuminating gas; as, for instance, in a porous or cracked muffle heated by gas. Heated in such a muffle the tests might give very bad results, whereas had the heating been done in a forge the results would have been quite satisfactory. Iron rendered brittle in this way becomes like ordinary iron if annealed in air or nitrogen. Even temperatures considerably below a red heat will, however, do this wholly or in part, as the author's experiments show. The metals low in carbon needed only to be heated to 200° or 250° to be rendered soft. The higher carbon metal required a higher temperature. The low carbon metal improved greatly even by lying at ordinary temperatures for a fortnight; but here, too, the higher carbon metal showed less satisfactory results. Two samples hardened at 800° C., the one after heating in air and the other after heating in hydrogen, the latter being brittle, were examined as to texture and found to be identical both in this respect and in their specific gravities. The latter sample was found to yield 0·00019 per cent. of hydrogen when heated to redness. To ascertain this a current of nitrogen was passed over the heated iron, and the hydrogen evolved burnt and weighed as water. The bending results are given of a large number of tests.

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* *Stahl und Eisen*, vol. xx. pp. 837–844.

E. Heyn* gives the results of an investigation of the action of water on iron.

Corrosion of Iron and Steel.—The relative corrosion of wrought iron, soft steel and nickel steel is discussed by H. M. Howe,† and the inferences are drawn—

1. That the difference in the rate of corrosion between wrought iron and soft steel is rarely enough to be of great moment except, perhaps, in marine boilers.

2. That the ratio of the corrosion of given soft steel to that of given wrought iron may vary greatly with the conditions of exposure.

Different observers have published very divergent results, but so much appears to depend on quasi-accidental variations and on the environment, that sometimes one and sometimes the other is more durable. In wrought iron and steel the cinder and the cementite respectively have a twofold action, one preventative, resisting oxidation, and the other electro-chemical, which, by the difference of potential, may sometimes hasten and sometimes retard oxidation. The resultant of these actions will vary both with the attacking medium and also with the progress of the action. The author has in progress a large number of experiments, but the following table summarising the results already obtained shows the relative corrosion of soft steel, wrought iron and nickel steel, taking wrought iron as a standard:—

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* *Mittheilungen der königlichen technischen Versuchs-Anstalt*, 1900, p. 38.

† Paper read at the International Congress on Methods of Testing the Materials of Construction.

	Sea Water.	Fresh Water.	Weather.	Average.
Wrought iron	100	100	100	100
Soft steel	114	94	103	103
3 per cent. nickel steel	83	80	67	77
26 per cent. nickel steel	32	32	30	31

D. H. Maury[*] discusses the electrolysis of underground metallic structures, especially in relation to pipes and rails affected by electric currents. Numerous illustrations are given to show the effects of corrosion thus produced. It would seem that the only way of preventing the corrosion is to keep the currents out of the ground by using return conductors properly insulated on all electric tramways.

M. Rudeloff[†] discusses the degrees of resistance to a rusting action shown by the wires of wire ropes. The results are given of numerous experiments relating to this. It was found that rusting did not affect the mechanical properties of the unrusted metal remaining in the wire. With regard to the influence exerted by variations in the composition of the metal forming the wires on the way these rusted, it was found that, despite variations in the percentage of manganese, carbon, and phosphorus in the metal forming the series of wires tested, and despite of very differing degrees of mechanical treatment, they were practically equal in their resistance to a rusting action. Rusting diminishes the elongation of the metal, and this diminution is relatively the greater the greater the degree of elongation of the metal before rusting. The tensile strength is also diminished, and the degree, as also in the case of the elongation, appears to be proportional to the duration of the rusting. The degree to which the wires could be bent and twisted was most seriously affected by rusting at the commencement. After seven months' exposure to rusting this seemed to have almost entirely ceased to have any influence on these last-mentioned properties. In the case of the sample of wire rope on which these experiments were originally based, and which had failed after being used in a place where it had been subjected to a considerable rusting action, it was found that this rusting had rendered the rusted wires distinctly brittle, while the reduction of area had been diminished by as much as 10 per cent. in the worst portion.

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[*] Paper read before the Water Works Association, Richmond, Virginia, 1900, through the *Engineering News*, vol. xliv. pp. 38–42.

[†] *Mittheilungen aus den Königlichen technischen Versuchsanstalten zu Berlin*, Part iii. pp. 107–129.

Manufacture of Ferro-Chromium.—W. Borchers [*] describes the manufacture of ferro-chromium. Powered chromite is intimately mixed with 12 to 15 per cent. of charcoal, 6 to 7 per cent. of resin or pitch, 5 per cent. of glass scrap, and 10 to 12 per cent. of quartz sand. The mixture is fused in luted clay or graphite crucibles in a Siemens furnace, or in a special regenerative crucible furnace, of which an illustration is given. Similar proportions for the manufacture of ferro-tungsten are given by the author.[†]

The Utilisation of Calcium Carbide.—An account is published by Liebetanz [‡] of the manufacture of calcium carbide, and of the utilisation of the latter in iron smelting. The author considers the question historically, describing both the earlier experiments and modern methods of manufacture.

C. S. Bradley [§] describes the manufacture of silicides of barium, strontium, and calcium, and states that some of them have been used as additions to steel to remove phosphorus, sulphur, and oxygen.

Tungsten Steel.—The occurrence and use of tungsten is described by A. C. Ross.[‖] It is usually found associated with tin, and in an ore known as wolfram or wolframite. The metal is especially valuable as an alloy for steel, on account of its hardening, toughening, and self-tempering qualities. It only requires 9 per cent. of tungsten to be alloyed with steel to give a self-tempered tool steel of great durability. "Mushet" steel, manufactured at Sheffield, contains this percentage, and sells for seven times as much as the highest priced ordinary tool steel. It is conceded to be the best steel made for machine tools. It does not twist in hardening, is easy to forge, file, or tool, and machines may and should be driven at a speed far in excess of any that can be used with any other steel. Tungsten steel has marked magnetic properties. The production of the metal to-day in the world does not exceed 1000 tons, and the demand exceeds the supply. Some particulars of the Nova Scotian deposits were given by C. A. Meissner, including the following analysis:—

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[*] *The Mineral Industry*, vol. viii. pp. 92–96.

[†] *Ibid.*, pp. 632–633.

[‡] Paper read before the *Eisenhütte Oberschlesien; Stahl und Eisen*, vol. xx. pp. 248–256, with seven illustrations.

[§] Paper read before the British Association, Bradford meeting, 1900.

[‖] *Journal of the Mining Society of Nova Scotia*, vol. v. pp. 31–35.

	Per Cent.
Tungsten trioxide	66·32
Silica	6·25
Manganese	12·02
Iron	0·12

In the case of the real wolfram the percentage of iron is much higher, and this tungsten ore must rather be called a hibrenite. It is a difficult ore to mine, occurring in bunches in the vein, which itself twists about in an extraordinary manner. Deposits are worked in Germany, Bohemia, and Texas, and it has recently been found in Nevada. It also occurs in the Cornish tin mines.

Iron Selenides.—According to H. Fonzes-Diacon * the combination of iron and selenium at high temperatures always gives rise to compounds containing an excess of selenium over that indicated in the formula FeSe. Amorphous products only are obtained by the action of hydrogen selenide or selenium vapour on red hot iron. Ferric selenide, Fe_2Se_3, produced by the action of hydrogen selenide on ferric oxide heated to bright redness, forms a grey, micro-crystalline powder with a blue reflex.

The selenides Fe_3Se_4 and Fe_7Se_8 are obtained in a similar manner from the peroxide or anhydrous ferric chloride at somewhat higher temperatures; these compounds are crystalline, and belong apparently to the cubic system.

Iron diselenide, $FeSe_2$, prepared in a similar manner in a dull red heat, forms pseudomorphs after crystallised anhydrous ferric chloride; when heated in a current of oxygen, it is oxidised to ferric oxide and selenium dioxide.

The higher selenides are all converted into the monoselenide by reduction with hydrogen; the subselenide Fe_2Se, however, could not be obtained by this process. When the monoselenide is heated in the electric furnace, a portion undergoes complete dissociation, whilst the residue remains unaltered. The stability of the selenides towards hydrogen-chloride or a concentrated solution of this gas increases with the percentage amount of selenium, the diselenide not being attacked. The selenium in these compounds is readily replaced by chlorine, and fuming nitric acid converts them into selenites.

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* *Comptes Rendus*, vol. cxxx. pp. 1710-1712; *Journal of the Chemical Society*, vol. lxxviii. p. 546.

Aluminium and Magnesium Alloys.—The alloys of aluminium and magnesium are described by Miethe.* Their properties are mentioned, and those consisting of relatively much aluminium and little magnesium are stated to be the most important, especially those with from 25 to 30 per cent. of magnesium. Another alloy of a useful character contained from 7·5 to 10 per cent. of magnesium, which is quite as good as the best brass.

Compounds Isolated from Steel.—A. Carnot and Goutal at the Paris International Congress on Applied Chemistry presented a paper dealing with the isolation from certain irons and steels, by chemical means, of compounds containing silicon, sulphur, phosphorus, arsenic, manganese, chromium, tungsten, and molybdenum.

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* *Stahl und Eisen*, vol. xx. pp. 921–923.

CHEMICAL ANALYSIS.

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I.—*ANALYSIS OF IRON AND STEEL.*

The Atomic Weight of Iron.—T. W. Richards and G. P. Baxter* have made a preliminary series of seven determinations of the atomic weight of iron by reducing ferric oxide to metallic iron. Their results seem to show that the generally accepted figure, 56, is slightly too high, and that the true value is very near 55·88.

Statement of Analysis.—H. S. Washington † makes a plea for uniformity in the order of stating the constituents determined in analyses of rock, and gives a list which it is proposed should be followed.

The lack of uniformity applies not only to rock analysis, but to all other analyses, and a general system of uniformity in each particular case would be very advantageous.

A Bibliography of Steelworks Analysis.—H. Brearley ‡ has continued the publication of his bibliography of steelworks analysis. All the papers relating to the subject published in the Journals of the Iron and Steel Institute, the Chemical Society, and the Society of Chemical Industry are classified and briefly abstracted.

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* *Proceedings of the American Academy of Arts and Sciences*, vol. xxxv. No. 13; *Chemical News*, vol. lxxxi. p. 174; *Zeitschrift für anorganische Chemie*, vol. xxiii. p. 255.

† *American Journal of Science*, vol. x. pp. 44-54.

‡ *Chemical News*, vol. lxxxi. pp. 49, 64, 76; vol. lxxxii. pp. 6, 18, 26, 42, 180, 185, 197.

Micro-Chemical Analysis.—A recent article * discusses the use of micro-chemical methods of analysis as adapted to iron and steel. They are given as quantitative only, but are of extreme delicacy, and capable of detecting very minute traces of silicon, tungsten, sulphur, manganese, chromium, nickel, cobalt, and copper. It is possible, however, that they may be used to some extent as indicating the quantities present. The methods are described in some detail. For silicon the metal is dissolved in nitric acid, and the solution is heated in a platinum spoon with sulphuric acid until the residue is nearly dry. Ammonium fluoride is then added, with a small drop of water, and the spoon is covered with a similar platinum spoon which has been cooled by water. Sublimation is then carried out, the sublimate being received on the moistened spoon. By this means hydrofluosilicic acid is formed, which on the addition of sodium chloride forms sodium fluosilicate. This salt crystallises on a varnished slide in characteristic hexagonal plates and stars, and in more concentrated solutions in elegant six-rayed rosettes, with a faint rose tint and sharp outlines. Phosphorus is shown as phospho-molybdate, and the remaining solution will show very minute traces of silicon as a rubidium silico-molybdate with the use of proper reagents. Sulphur is shown by the formation of crystals of sulphate of calcium or of lead, manganese as oxalate, chromium as chromate of silver or lead, tungsten as thallous tungstate, cobalt as the double nitrate of potassium and cobalt, and both nickel and copper are best seen in the triple nitrates with lead and potassium.

Determination of Carbon.—B. Blount † has made experiments to ascertain whether the carbon in steel can be determined by the direct combustion of the steel filings. He found that if the filings without further subdivision are placed in a porcelain tube heated by a Fletcher burner to 700° or 800° C., and a current of oxygen is passed over them, the combustion of the carbon commences at a rapid rate, but that an oxide layer soon forms on the steel which prevents the further oxidation of the carbon. The author then used a flux, such as lead oxide, to remove this oxide film, but the results were unsatisfactory in that no tube used would resist the action of the litharge. If, however, the steel was raised to a temperature of 1100° to 1200° C., the combustion of the carbon in from 3 to 5 grammes of filings is completely effected, and that within the space of an hour. Metallic iron particles will be left, but they are quite free from carbon. Here again, however, the tubes offer difficulties. They will not stand the high temperature for long, and frequently fracture during the experiments. Heating in oxygen even to 1200° C. does not enable the sulphur to be determined. A portion is burnt out, but more than 20 per cent. remains in the iron. The peculiarity of "kernel roasting" is observed in this case, the sulphur segregating into the iron kernel.

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* *Colliery Guardian*, vol. lxxx. pp. 267–269.

† *The Analyst*, vol xxv. pp. 141–144.

F. Ibbotson [*] and H. Brearley give some methods for the analysis of tungsten compounds. Carbon is determined by ignition with oxides of lead.

George W. Sargent [†] describes a modification of the ordinary process of burning the carbonaceous residue of iron and steel in a current of air or oxygen. The air or oxygen employed is first passed over a red-hot spiral made from a platinum tube 17 inches long and 5·32 inches in diameter. This gives four close coils ¾ inch in diameter, and leaves 4 inches extended on either side. The object is to fully oxidise any hydrocarbons which may be present in the air, and the carbon dioxide formed is then absorbed in a Geissler bulb apparatus. The carbon is placed in a porcelain boat heated inside a porcelain combustion tube and the resulting gases are passed through a tube containing red-hot copper oxide to ensure complete oxidation. It has been found that the same object is attained by passing the gases through a small glass tube in which two platinum wires were fused, so that a spark would be produced between the points, when a current from a Rhumkorff coil passed through the wires. As there is, however, always a danger of stoppage, the use of copper oxide is the safest. To retain traces of hydrochloric acid or chlorine, the gases are afterwards passed through a ½-inch glass tube 6 inches long, containing loosely packed coarse wet sand held in place by two small discs of copper gauze placed at either end.

Precautions are taken to prevent overheating of the corks. The dried gases are then finally absorbed in a weighed Geissler apparatus of somewhat larger size than usual, and containing 30 cubic centimetres of aqueous caustic potash of 1·27 specific gravity.

G. Auchy [‡] discusses the Dougherty method for the determination of carbon in steel. In this method the carbon sponge is first washed four times with hot nitric acid to remove copper and copper sulphide before it is ignited. Of the loss, 67·5 per cent. is calculated as carbon. Auchy shows that washing with nitric acid causes a loss of carbon, and that the carbon sponge retains nitric acid, and on the average only contains 60 per cent. of carbon. The limits of error of the process are about 10 per cent. In the ordinary methods of combustion it is pointed out that difficulty is experienced in preventing the escape of small quantities of carbon dioxide and moisture from the potash apparatus. The author, to avoid this, employs a slow combustion, and uses sulphuric acid instead of calcium chloride to ensure a more steady flow of gas.

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[*] *Chemical News*, vol. lxxx. p. 293.

[†] *Journal of the American Chemical Society*, vol. xxii. pp. 277-285.

[‡] *Ibid.*, pp. 334-343.

A. B. Harrison * describes a modified form of Eggertz' method for determining graphite in pig iron. One gramme of the sample is dissolved in 100 cubic centimetres of hydrochloric acid if it is white iron, or in nitric acid of 1·13 specific gravity if it is grey or foundry iron. This is filtered, and the filtrate is passed through a tared paper. After successive washings with acid, water, alcohol, and ether, the filter and residue are ignited and the ash weighed. The difference is graphite.

Determination of Manganese.—According to A. Mignot,† the sample is dissolved in twenty-five times its weight of nitric acid of sp. gr. 1·2, heated to boiling, diluted with water, and mixed with three times its weight of bismuth tetroxide. The pink solution is then filtered through asbestos, and the permanganic acid titrated with hydrogen peroxide. The process is not applicable in the presence of chromium if this exceeds 1 per cent. Bismuth tetroxide is prepared by fusing in an iron dish equal parts of bismuth subnitrate and potassium chlorate with two parts of sodium hydroxide; the mass is then extracted with water to remove the alkali and dried.

The determination of manganese in steel by the permanganate method is discussed by H. Jervis.‡

Determination of Phosphorus.—F. Ibbotson § and H. Brearley describe a method for the estimation of phosphorus in steel which is believed to be new in respect to the means employed. An outline of the process applied to steels is as follows:—Dissolve 2 grammes of the sample in 45 c.c. 1·20 nitric acid, add permanganate until a pink colour or a manganese oxide precipitate persists after a few minutes' boiling, clear with ferrous sulphate, add about 4 c.c. strong ammonia, and then to the clear hot solution 30 c.c. of the molybdate reagent. Shake the stoppered flask, allow to stand a few minutes at 70° to 80° C., pass through a small pulp filter, wash, dissolve off yellow precipitate with a few drops of ammonia, clearing the sides of the flask with the same solution as it drops from the end of the funnel, pass solution again through the filter into a small beaker (200 c.c.), and wash. Add 10 to 12 c.c. hydrochloric acid, 10 c.c. lead acetate (40 grms. per litre), and heat. In the washed-out flask heat a mixture of ammonium chloride (=10 to 12 grms. NH_4Cl) and 50 c.c. strong ammonium acetate; mix the two solutions in the flask with shaking, filter, and weigh as $PbMoO_4$. The weight multiplied by 0·007 gives the weight of phosphorus in the steel. The operation is very conveniently performed with batches of four, which are completed in an hour and a half. A single estimation takes about forty minutes.

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* *Proceedings of the Engineers' Society of Western Pennsylvania*, vol. xvi. pp. 117–118.

† *Annales de Chimie analytique*, vol. v. pp. 172–177.

‡ *Chemical News*, vol. lxxxi. p. 171.

§ *Ibid.*, vol. lxxxii. p. 55.

Some noteworthy features of the process are:—The $PbMoO_4$ is quite insoluble in the solutions used; being very granular it filters well, and it can be ignited speedily without loss of weight, and it weighs more than one hundred and forty times heavier than the phosphorus to be estimated.

Determination of Silicon.—H. Bornträger * finds that the solution of ignited ferric oxide in hydrochloric acid is more easily effected by adding some manganese dioxide. Apparently this is due to the chlorine liberated.

F. W. Bauer † gives the variations by six different methods of determining silicon in ferro-silicon as ranging from 15·17 to 16·25 per cent. Direct fusion with sodium carbonate gives the lowest results.

Determination of Sulphur.—M. J. Moore,‡ in connection with the supposed gain of sulphur in malleable castings after annealing, refers to the influence of treatment of the metal on the method of determination. When the evolution method is followed, the sulphur sometimes passes off in a form not soluble in the absorbent, and so escapes estimation. A number of results are given to show the difference between the gravimetric and volumetric methods on chilled samples and on samples cast in sand.

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* *Zeitschrift für Analytische Chemie*, vol. xxxviii. p. 774.

† *Iron Trade Review*, May 31, 1900, p. 20; *Iron Age*, May 31, 1900, p. 11.

‡ *Iron Age*, May 3, 1900, pp. 25–26.

The volumetric determination of sulphur in cast iron and steel is discussed by J. Thill.*

Determination of Slag.—L. Schneider † observes that the determination of slag in iron is accompanied with some difficulty. The slag itself is not of uniform composition, but it consists chiefly of silica and the oxides of iron and manganese. In one and the same operation, too, slags of varying composition may be met with. Thus in rolling, the first portion of the slag which is squeezed out is more fluid and richer in silica than that which is got rid of at a later stage of the process. As the slag does not alloy with the iron, it exists more or less finely disseminated in the metal. The larger portions can be readily observed with a lens, and the microscope shows the smaller portions as sharply defined spots. Ledebur believes that, in addition to these slag particles, iron containing carbon, silicon, and manganese in very small quantities may also contain in solution the lower oxides of iron, manganese, chromium, &c.

The author divides the methods that are employed for the determination of slag in iron and steel into two main classes:—(1) Those which yield too low a result, and (2) those which are likely to give results that are too high. To the first group belong such methods as the ignition of the metal in a current of chlorine, and those in which the solution is aided by the use of acids. To the second group belong methods in which the solution is effected by agents that act but slowly on certain constituents of the steel. The various constituents of steel behave differently to solvents. To those which dissolve least readily belong the phosphide and carbide of iron. These are only very slowly or incompletely brought into solution by the action of the chloride of copper or mercury, or bromine or iodine, the difficulty with which the solution is effected varying with the percentages of those constituents that are present in the metal. The author shows, by the aid of experimental results, that the method which depends on testing the metal in a current of chlorine does not, as is sometimes stated, give accurate results, and is indeed quite valueless, as the results may be far too low. Results that are too low are also obtained in the case of all methods in which inorganic acids are used in the solution of the steel. Such acids dissolve slag as well as metal. Even very dilute acids, the author finds, dissolve considerable quantities of slag. Thus when slag which had been squeezed out of a puddled rail was treated with water containing 5 per cent. of nitric acid, 58 per cent. of the slag passed into solution. A portion of the slag, however, resists the action of even strong nitric acid. Thus samples of iron that contain slag leave some of this slag undissolved after treatment with a mixture of one part of nitric acid with two parts of water. Hydrochloric acid exerts a still stronger solvent action.

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* *Zeitschrift für Analytische Chemie*, vol. xxxviii. p. 342; *Chemical News*, vol. lxxxi. p. 54.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. pp. 257–260, 275–277.

To the second group of methods, giving results that are too high, belong the Eggertz methods so frequently employed. These consist in principle of dissolving the iron by bromine or iodine in the presence of water, the slag being left as a residue. The author has shown that phosphides of iron and manganese may also be found in the residue left after treatment with copper chloride. Iodine and bromine also give different results. Thus P. R. von Mertens found in the same sample of weld iron 0·93 per cent. of slag when bromine was used as the solvent, and 2·02 per cent. when iodine was employed. The author has obtained similar results. The residue after the use of iodine contained particles of iron. Even when bromine is used, such metallic particles may be left, as the author shows in the cases of four samples of steel. The residues left were all high in phosphorus—in one case to the extent of 14·2 per cent. Of all the customary solvents, bromine is the one that acts most strongly on those metallic compounds occurring in iron and steel that are difficult to dissolve. Its action, however, is very considerably less energetic if, with the addition of a bromide, it has been brought into aqueous solution. If, for instance, steel is shaken up frequently for several days with a solution of bromine in potassium bromide, a metallic residue will still remain. Well-marked constituents of steel separate out as a fine grey powder. The aqueous solution of bromine in iron bromide also acts somewhat feebly. To make the action complete the solution must be heated. The method which the author recommends is the following:—Place 15 cubic centimetres of bromine, and on this 100 cubic centimetres of water, in a beaker which will hold from 200 to 300 cubic centimetres. Then place this beaker in another containing water, to avoid too rapid an action when the iron commences to pass into solution. Next, charge in five grammes of the sample in some finely divided form, and shake the solution. Continue dissolving in the cooled beaker until no metallic particles remain at the bottom, and no solid grains can be felt with a glass rod. This apparent solution of the metal is complete in two or three hours. If comparatively larger percentages of carbon and phosphorus were present in the metal, the residue will be found to contain extremely finely divided particles of iron compounds which dissolve only with difficulty. To bring these, too, into solution, the action of the bromine must be increased by the application of heat. This is done by heating the water in the outer beaker to about 90° C. for ten or fifteen minutes. The water in the outer beaker is in quantity sufficient to cause the other beaker with its contents to float and not touch the bottom of the outer beaker. The residue is afterwards allowed to settle, and is then filtered through a small filter-paper, and washed with water at ordinary temperature until ammonium sulphocyanide shows no iron reaction with the filtrate. Notwithstanding this, both the carbonaceous residue and the filter-paper still retain absorbed basic iron bromide. To get rid of this, the filter-paper and its contents are washed with a boiling solution of ammonium tartrate, containing considerable quantities of ammonia. If the sample of metal was high in carbon, and consequently left a bulky residue on the filter, this residue must be first washed off the filter and boiled with the above solution for a short time. All the iron will in this way have been removed from the filter-paper and residue, and ammonium sulphide must subsequently not produce a brown coloration in the filtrate. If it does, this shows that iron carbides and phosphorus compounds have remained in the residue, and that these are being decomposed little by little by the ammoniacal solution. Testing in this way, the second filtrate affords an unfailing test as to the freedom of the slag from metallic admixtures. The filter-paper is finally washed with hot water and incinerated in a platinum crucible. If the ignited residue is coloured brown from separated slag, it is freed from admixed silica by boiling with a solution of sodium carbonate and again igniting. It is then weighed. Repeated ignition in an open crucible causes the magnetic oxide of the slag, if this is present in but small quantity, to pass completely into ferric oxide, and this must be borne in mind when making the subsequent calculations.

The author also draws attention to the care that must be taken in sampling the metal, and gives analytical results showing how greatly the percentages of contained slag may vary in different portions of the same rail. The drillings or filings should not be too small, and should be taken from a clean surface. If the filings taken are too small, the smaller particles of slag are readily lost.

The Analysis of Chrome and Tungsten Steel.—A. G. M'Kenna [*] describes his methods for the complete analysis of chrome and tungsten steels. Five grammes of the broken sample are dissolved, by boiling, in a 500 cubic centimetre evolution flask with 30 cubic centimetres each of hot water and hydrochloric acid. The gas is passed into ammoniacal cadmium chloride, which is then titrated for sulphur with iodine and starch. To the solution 10 cubic centimetres of strong nitric acid is added, and it is boiled to dryness, taken up with 15 cubic centimetres of strong hydrochloric acid, evaporated, and again taken up with 20 cubic centimetres of the acid, and diluted to 100 cubic centimetres. Silica and tungstic acid are filtered off and washed with 5 per cent. nitric acid and ignited. After weighing, the silica is driven off with hydrofluoric acid, and the remaining tungstic acid is weighed. The filtrate is evaporated to a small bulk, 50 cubic centimetres of acid are then boiled in it to expel hydrochloric acid, and after fumes cease the solution is made up with nitric acid to 200 cubic centimetres; 10 grains of potassium chlorate are added to the boiling solution, which is then evaporated to 75 cubic centimetres. The manganese is thus precipitated as MnO_2 and filtered on an asbestos plug. Chromium is titrated with ferrous sulphate and permanganate in the solution diluted to 500 cubic centimetres. Phosphorus is determined by molybdate in a separate portion from which silica and tungstic acid are separated. Carbon is determined by ignition of the residue left after solution in potassium copper chloride.

Determination of Nickel.—R. Fieber [†] adopts a colorimetric method for the determination of nickel. If steel containing nickel is dissolved in nitric acid, and the iron precipitated by ammonia, the degree of intensity of the blue coloration of the filtrate is proportional to the percentage of nickel present. The presence of relatively large percentages of chromium interferes with this result. Standard solutions are prepared, which are then used for the purposes of comparison with that resulting from the solution of the steel under examination. To prepare these, 6 grammes of metallic nickel, the percentage of nickel in which has been accurately determined, is dissolved in nitric acid, slightly evaporated, transferred to a 200 cubic centimetre flask, the iron precipitated by ammonia, allowed to cool, shaken, and then filtered. The standard solutions are made to differ by 1 per cent. from each other. With less than 1 per cent. of nickel present in the sample under test the results obtained become uncertain. It is pointed out in *Stahl und Eisen*[*] that it is evident that if the results obtained are to be at all accurate, it would be necessary to have approximately the same quantities of iron in the case of the sample and of the check, or otherwise the iron precipitates would retain different quantities of nickel, and so render the process untrustworthy.

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[*] *Proceedings of the Engineers' Society of Western Pennsylvania*, vol. xvi. pp. 119-121.

[†] *Chemiker Zeitung*, vol. xxiv. pp. 393-394.

G. W. Sargent[†] describes the method he employs for the determination of nickel in nickel steel.

E. Janda[‡] separates cobalt and nickel by adding to the feebly acid solution an equal volume of glacial acetic acid, boiling, and then adding to this boiling solution a solution of nitroso-b-naphthol in acetic acid of 50 per cent. strength. Cobalt falls out as a voluminous precipitate, while nickel remains in solution.

F. Ibbotson[§] and H. Brearley discuss the separation of nickel and iron with ammonia.

Determination of Molybdenum.—E. Döhler[‖] determines as follows the molybdenum contents of iron:—Dissolve 10 to 20 grammes of the iron, or less if the molybdenum contents is high, in 100 cubic centimetres of nitric acid, evaporate, take up with 100 cubic centimetres of hydrochloric acid, evaporate down to some 10 cubic centimetres, dilute, and filter into a flask that will hold 1·5 litre. The whole of any tungsten present in the iron will be found in the residue, which, however, is free from molybdenum if silicon and graphite do not exceed 1 per cent. The filtrate is diluted to a litre, raised to a temperature of 80° C., and sulphuretted hydrogen is then passed through. The whole of the molybdenum is precipitated. Allow the molybdenum sulphide to settle for about twelve hours; filter; wash well with sulphuretted hydrogen water acidulated with hydrochloric acid, and, after boiling down the filtrate somewhat, test it again for molybdenum with sulphuretted hydrogen. The molybdenum sulphide precipitate is washed with a flask with hot ammonium sulphide solution. If any molybdenum sulphide should remain on the filter paper that cannot be removed by hydrochloric acid, the paper must be incinerated, and the residues fused with soda and sulphur. The various solutions containing the molybdenum are mixed together, heated for two or three hours, filtered, again heated nearly to boiling, and then the molybdenum is precipitated by hydrochloric acid of 1·124 specific gravity. The whole is then boiled until no more sulphuretted hydrogen can be detected, and is subsequently filtered through a weighed filter, and dried at a temperature of 120° C. A portion of the precipitate on the filter is subsequently ignited in a current of oxygen until the weight is constant and the molybdenum contents is calculated from the weight of the molybdenum sulphide, MoS_2, so determined.

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[*] Vol. xx. p. 796.

[†] *Journal of the American Chemical Society*, vol. xxi. No. 10; *Chemical News*, vol. lxxxi. p. 209.

[‡] *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. p. 303–305.

[§] *Chemical News*, vol. lxxxi. p. 193.

[‖] *Chemiker Zeitung*, vol. xxiv. p. 537.

The estimation of molybdenum in steel and steel-making alloys is exhaustively discussed by F. Ibbotson * and H. Brearley.

II.—*ANALYSIS OF IRON ORES AND SLAG.*

Determination of Iron.—L. Blum † considers the question of the determination of iron in tap-cinder. Such determinations made by the permanganate or stannous chloride methods frequently show varying results, due, the author shows, to the almost unfailing presence of vanadic acid. The reducing agents employed reduce the vanadic acid as well as the ferric salt, and it subsequently again oxidises and appears as so much iron in the results. Accurate determinations are only possible by the use of elaborate gravimetric methods. The author dissolves half a gramme of the substance, separates the silica, neutralises with ammonium carbonate, dilutes, and precipitates boiling with ammonium acetate. The precipitate is again dissolved, reprecipitated, washed, dissolved in hydrochloric acid; tartaric acid is added, and the iron is then precipitated by ammonium sulphide. The precipitate is allowed to settle for a considerable time. Vanadium sulphide, phosphoric acid, lime, and alumina remain in solution. The iron sulphide is washed with water containing ammonium sulphide, dissolved, oxidised, precipitated with ammonia, and determined in the ordinary manner. When the cinder itself is fused with potassium-sodium carbonate, or when it is dissolved direct in nitro-hydrochloric acid or in bromo-hydrochloric acid, any vanadium it contains is oxidised to vanadic acid, and this then interferes with titration for the reasons stated.

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* *Chemical News*, vol. lxxxi. pp. 269–271.

† *Zeitschrift für Analytische Chemie*, vol. xxxix. pp. 156–157.

Determination of Manganese.—The electrolytic method employed in Brazil for the determination of manganese in manganese ores is described by A. Hiorns.* The ore averages 55 per cent. of manganese, and 0·05 gramme is considered ample for its proper determination.

J. and H. S. Pattinson † discuss the determination of manganese as sulphide.

Determination of Lime.—It is customary ‡ in determining the percentage of lime in slags and iron ore to first separate the silica, and oxidation by bromine having been effected, to throw down the iron, alumina, manganese, and any small quantities of phosphoric acid, in the filtrate by ammonia, and then subsequently to separate the lime in the filtrate as oxalate.

L. Blum § shows that this iron-alumina precipitate always carries down lime as well, and he recommends that all the lime should be thrown down without first separating this precipitate. This he does by first adding enough tartaric acid to prevent any precipitation when ammonia is added. In making the analysis, he dissolves five grammes of the slag in hydrochloric acid, separates the silica as usual, dilutes the filtrate to 500 cubic centimetres, takes 50 cubic centimetres of this, adds a solution of tartaric acid, then an excess of ammonia, and precipitates boiling with ammonium oxalate. The calcium oxalate is heated in a closed platinum crucible, and converted into oxide. Ores are treated in exactly the same way. The author points out that this method is not absolutely accurate, in that, in the first place, the lime precipitate is not absolutely pure, and, in the second, that the precipitate is not completely insoluble in the solution used in precipitation, but he adds that these errors are so slight that they need not be taken into consideration, provided manganese is not present in any large quantity. As the percentage of manganese increases, the results obtained become higher and higher, owing to the fact that manganese oxalate is precipitated with the calcium oxalate. This may also be seen from the colour of the ignited precipitate.

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* *Chemical News*, vol. lxxxi. p. 15.

† *Ibid.*, p. 193.

‡ *Stahl und Eisen*, vol. xx. p. 797.

§ *Zeitschrift für Analytische Chemie*, vol. xxxix. p. 152.

Determination of Tungsten.—H. Bornträger* decomposes tungsten ores and residues by fusing one gramme of the finely powdered material for an hour with 10 grammes of calcined soda and heating until the whole is in a state of clear fusion. It is afterwards extracted in the hot, diluted to 250 cubic centimetres, cooled, and filtered. Each 100 cubic centimetres of the filtrate is then equivalent to 0·4 gramme of the substance, and to this quantity of solution there is added 15 cubic centimetres of nitric acid and 45 of hydrochloric acid, and the mixture is then evaporated to dryness in a porcelain dish. The extraction is subsequently made with a solution consisting of 100 grammes of ammonium chloride, 100 grammes of hydrochloric acid, and 1000 grammes of water, then filtered, and the residue washed with hot ammonia. This residue may consist of silica, tungstic acid, and stannic acid. To the filtrate nitric and hydrochloric acids are added and the whole again evaporated to dryness. The tungstic acid so obtained is free from silica and oxide of tin, and after ignition can be weighed direct. If metallic tungsten, containing oxygen, carbon, antimony, iron, and silica is to be analysed, it is ignited for half-an-hour and some nitre then added to the ignited material. Tungsten alloys are treated in a similar way. The author considers that the determination of tungsten by precipitation with mercury leads to very inaccurate results. Commercial tungsten contains from 95 to 97 per cent. of that element.

As the accurate analysis of tungsten ore is a lengthy operation, the author recommends the use of a rapid method which enables the tungstic acid to be very rapidly determined, and gives results that are accurate within 5 per cent. The ores consist of ferrous and manganous tungstates, rendered impure by sand, lime, magnesia, antimony, tin, lead, cobalt, nickel, and copper. One gramme of the finely divided ore is fused for an hour with 10 grammes of soda, and then extracted, filtered, and weighed. If the weight of the residue is subtracted from 100, the approximate percentage of the tungstic acid is at once obtained.

Analysis of Chrome Iron Ore.—According to R. Fieber,† 0·5 gramme of the finely powdered ore is fused in a platinum crucible with three grammes of sodium potassium carbonate for 10 minutes; when cold, three grammes of dry borax are added, and the mixture is again fused by first heating for a short time over the flame of a Teclu burner, and then for 45 minutes over the blowpipe. If the decomposition is not yet complete, a further addition of sodium potassium carbonate should be made. It is not really necessary to use the blast; if time is no object, a prolonged heating over the flame of a large Teclu burner will answer the purpose.

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* *Zeitschrift für Analytische Chemie*, vol. xxxix. p. 306; *Stahl und Eisen*, vol. xx. p. 995.

† *Chemiker Zeitung*, vol. xxiv. p. 333; *Journal of the Chemical Society*, vol. lxxviii. p. 512.

Fieber's method is adversely criticised by R. W. E. MacIvor,* who gives details of the borax method he prefers.

Analysis of Titaniferous Iron Ores.—Charles Baskerville† states that silica is estimated in the usual manner after fusing one gramme of the ore with five grammes of sodium carbonate and one gramme of potassium nitrate. After weighing the crude silica, it is heated with hydrofluoric and sulphuric acids and then re-ignited; the loss in weight represents pure silica.

Sulphur and phosphorus are estimated by fusing two grammes of the ore with 20 grammes of the above fusion mixture, using "gasolene" as a source of heat. The fused mass is then extracted with water, and to the filtrate are added 25 c.c. of ferric chloride in solution containing 0·1 gramme of metallic iron. Slight excess of hydrochloric acid is added, the liquid boiled, re-precipitated with ammonia, and the sulphuric acid estimated in the filtrate. The phosphoric acid is contained in the iron precipitate, and may be estimated by the molybdate process. Titanium is estimated by fusing with 0·5 gramme of sodium fluoride and 5 grammes of potassium hydrogen sulphate for 15 minutes. The fused mass is dissolved in boiling water containing 3 c.c. of nitric acid, ammonia is added, and the excess expelled by boiling. The well-washed precipitate is dissolved by diluted hydrochloric acid, and dilute ammonia is added until a slight permanent precipitate is obtained, which is then redissolved in a drop or two of dilute hydrochloric acid (1 : 100). The titanium is now precipitated as usual by saturating the liquid with sulphur dioxide and boiling for a few minutes; it is then collected, ignited, and weighed as dioxide. When many assays have to be made, Weller's colorimetric process is preferable. 0·5 gramme of the ore is fused with sodium fluoride and potassium hydrogen sulphate as directed, care being taken to completely expel the fluorine; the fused mass is dissolved in water containing 10 per cent. of sulphuric acid, and finally made up to 500 c.c. One hundred c.c. of the filtrate are then mixed with 5 c.c. of hydrogen peroxide, and the colour thus produced is compared with that of a series of ferruginous solutions to which a varying amount of titanium and 5 c.c. of hydrogen peroxide have been added. Iron is estimated by the bichromate method in the filtrate from the silica.

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* *Chemical News*, vol. lxxxii. p. 97.

† *Journal of the Society of Chemical Industry*, vol. xix. pp. 419–420.

III.—*FUEL ANALYSIS.*

Apparatus for Determining the Calorific Value.—Gaetano Magnanini and V. Zunino[*] describe a modified form of Lewis Thompson's calorimeter, in which the use of an oxidising mixture to burn the fuel is obviated, and the combustion carried on in a steady stream of oxygen. A series of fifteen different samples of coal were examined in the new apparatus and good results obtained, the calorific values found being in every case but two higher than the numbers yielded by the Lewis Thompson method.

Determination of Sulphur.—Pellet[†] deals with the determination of sulphur in coal and other bodies. The material is oxidised by fusion with a mixture of potassium nitrate and sodium carbonate. The aqueous solution is acidified, and the sulphur is precipitated as barium sulphate.

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[*] *Gazetta Chimica Italiana*, vol. xxxi. pp. 395–401; *Journal of the Chemical Society*, vol. lxxviii. p. 465.

[†] Paper read before the Paris International Congress of Applied Chemistry.

STATISTICS.

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I.—*UNITED KINGDOM.*

Mineral Statistics.—According to the official report issued by the Home Office,[*] the production of coal in the United Kingdom in 1899 amounted to 220,094,781 tons. The production during the previous year was 202,054,516 tons. The total quantity of iron ore raised in 1899 was 14,461,330 tons.

The production of pig iron in 1899 is officially stated to have been 9,421,435 tons. The estimate of the British Iron Trade Association was 9,393,018 tons. There were 411 furnaces in blast.

Iron Trade Statistics.—The British Iron Trade Association have issued the following statistics,[†] showing the production for the first half of 1900:—

	Tons.
Pig iron	4,540,403
Bessemer steel ingots	1,038,279
Open-hearth steel ingots	1,624,823

The position of the iron industry of the United Kingdom is discussed from a German point of view.* The production, imports, and exports of pig iron are tabulated as follows:—

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[*] *Mines and Quarries: General Report and Statistics for* 1899. Part III., Output. London, 1900.

[†] *Iron and Coal Trades Review*, vol. lxi. p. 845.

Year.	Production.	Imports.	Exports.
	Metric Tons.	Metric Tons.	Metric Tons.
1891	7,525,301	...	853,580
1893	7,089,318	35,923	853,391
1895	8,022,006	94,609	880,433
1897	8,930,086	160,531	1,219,958
1899	9,454,204	174,159	1,401,365

During the first nine months of 1900 the imports of pig iron into the United Kingdom were 96,077 tons as compared with 144,382 tons in 1899. In this latter year 91 per cent. of these imports came from the United States, Sweden, and Spain. The imports of pig iron from the United States were only 3727 tons in 1895, but as much as 82,284 tons in 1899. The exports to Germany amounted to 348,000 tons in 1897, 292,000 tons in 1898, and 438,000 tons in 1899; while to Holland it was 220,000 tons in 1897, 169,000 tons in 1898, and 266,000 tons in 1899. Of this, most evidently went to Belgium and Germany. Proof of this is obtainable from the fact that the German statistics show that the imports of pig iron from the United Kingdom in 1899 amounted to 530,000 tons, as compared with the 438,000 tons shown in the United Kingdom statistical returns. A marked feature of recent progress in the United Kingdom export iron trade is shown by the increase in the exports of ingots, slabs, &c., the exports of which in the first nine months of 1900 amounted to an excess of 177,443 tons over the imports of similar products. An interesting comparative tabular review shows the exports to the various colonies and to other countries in 1895 and 1899. The special feature in the statistics of recent years is believed to lie in the large increase in the imports of pig iron, semi-manufactures, and other iron trade products from the United States. At the same time the exports from the United Kingdom to the United States have undergone a diminution. Thus, in 1895, 6000 tons of rails were exported, and only 81 tons in 1899, while of tin-plate the exports fell from 225,000 tons in 1895 to 60,000 in 1899, and of pig iron in the same period from 42,104 tons to 36,317 tons, or 14 per cent.

Iron Ore Supply.—A report to the British Iron Trade Association by J. S. Jeans † deals with the iron ore supplies available for the British iron industry. Ten years ago the total consumption of iron ores throughout the world was computed at about 50 millions of tons, of which about 15 millions, or 30 per cent., were raised in the United Kingdom, and only a trifle over 12 million tons, or say 25 per cent., in the United States. Now the United States in 1899 produced about 25 million tons of iron ore, against little more than one-half of that quantity produced in the United Kingdom, and the total world output of iron ore has reached about 90 millions of tons, which is an increase of 80 per cent. on the output of 1888. The question as to whether the supplies that are available for the requirements of this country are likely to continue undiminished in volume and reasonable in cost is then considered in some detail, the resources of Spain, Greece, Turkey, Sweden, Norway, and the Colonies being referred to.

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* *Stahl und Eisen*, vol. xx. pp. 1077–1080.

† *Iron and Coal Trades Review*, vol. lx. pp. 1192–1194.

So far as Europe is concerned, the only competitive countries at present have no advantages over Great Britain. Indeed, most of them are less favourably situated, and all of them, like Great Britain, are compelled to import larger or smaller supplies from year to year, in order to supplement their own resources. In the United States it is otherwise.

If it be true—but this matter is not further discussed—that the quantity of hæmatite or Bessemer ores available for the purposes of the British iron industry is limited, whether at home or abroad, it is probable that increased attention will require to be given to the production of basic steel, and that the acid process must largely be discontinued. The output of basic steel in 1898 in the six leading countries was approximately as under:—

	Bessemer.	Open-hearth.	Total.
Great Britain, statute tons	517,379	294,688	812,067
United States ,,	...	2,000,000	2,000,000
Germany, metric tons	3,973,225	1,693,825	5,667,050
Belgium ,, ,,	...	95,000	95,000
France ,, ,,	535,059	...	535,059
Austria-Hungary ,,	125,000	170,000	295,000
Total	...	...	9,404,176

Coal Supply.—The coal reserves at the close of the nineteenth century are dealt with by E. Hull* in an address delivered at the annual meeting of the Victoria Institute, London. The question of the exports is considered, and the imposition of an export duty is advocated, as is also the appointment of a Royal Commission.

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* *Iron and Coal Trades Review*, vol. lxi. p. 121.

The threatened exhaustion of Britain's cheap coal supplies is dealt with by J. S. Jeans [*] in a series of articles, and a number of letters on the British coal resources and exports have been published.[†] Amongst the contributors are J. B. Simpson, E. Hull, T. Forster Brown, C. H. Vincent, D. A. Thomas, and G. Harwood.

II.—*AUSTRALASIA.*

Coal in Queensland.—In the Budget statement of the Hon. Robert Philp, Premier and Treasurer of Queensland, it was stated that the production of coal in 1899 was 494,000 tons, being an increase of 80,000 tons over that of the preceding year. Hitherto, the consumption of coal has been purely local; indeed, the mines have been unable to supply the requirements, the reason being the remoteness of the coal-beds from water-carriage. The increased demand for coal all over the world has no doubt been the cause of attention being again directed to the great stores of this article that the Colony possesses, and it seems probable that an effort will be made, not only to supply all local wants, but to look for markets outside the Colony. It is estimated that within the area of the Blair Athol coalfield—about five square miles—there are 7,000,000 tons of the finest quality of Clarmont coal, and about 56,000,000 tons of a slightly inferior quality in a lower seam not yet mined, irrespective of other seams that may exist at greater depths. A remarkable discovery of anthracite coal was lately reported to have been made on the Dawson River. The seam is 11 feet thick, and the coal is very heavy and compact. As the coal country extends westerly from the Dawson for many miles, the quantity of anthracite is enormous. No other coal of the same character has been found in Australia, so that the deposit will be a very material factor in metallurgical operations within the Colonies, and may become of international importance. As to Collide Creek, situate about 50 miles in a south-westerly direction from Gladstone, so long ago as 1892 the Assistant Government Geologist reported that, over the area already proved, there was sufficient coal to last for 150 years with an equal output to that of the whole Colony for that year—namely, 338,334 tons.

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[*] *Iron and Coal Trades Review*, vol. lx. pp. 931, 977, 1025.

[†] *Ibid.*, pp. 933, 978, 1028, 1223.

The coal-mining industry of Queensland is discussed elsewhere.*

The Mining Industry of New Zealand.—The Minister for Mines for New Zealand, in his statement for 1900, reports that continued progress is being made in all branches of the mining industry. The gross output of coal for the year was 975,234 tons, this being an increase of 68,201 tons as compared with 1898. In the North Island the coal output showed a falling-off amounting to 7262 tons, but that of the Middle Island is increased by 75,463 tons.

There are as yet no further developments with regard to the iron ore deposits in the Middle Island, or to the ironsand on the Taranaki coast. With a view to encouraging the introduction of sufficient capital for the erection of smelting works, the Government is prepared to consider favourably a proposal based on the following lines:—"That a company shall be formed with a capital of not less than £200,000; that of this £200,000, £100,000 shall be expended in acquiring lands, erecting buildings and the necessary plant and appliances; and this having been done, that the Government shall grant a bonus of £1 per ton on the first 24,000 tons of marketable iron or steel produced; that the iron or steel required for the Colony shall be taken from the company at a margin above the market rates ruling beyond the Colony, allowing freights."

Coal in Western Australia.—The Under-Secretary of Mines† reports that satisfactory developments have taken place in the Collie coalfield, the output having increased from 3508 tons in 1898 to 54,336 tons in 1899. The coal is being largely used on the Government railways and on the goldfields, and practical tests have proved its value as a naval fuel.

III.—*AUSTRIA-HUNGARY.*

Mineral Statistics.—An official report‡ has been published giving details of the area of the mining concessions in Austria, of the mining machinery in use, of the workmen employed, of the accidents that occurred during the year, and of the miners' provident clubs. In all the Austrian mines in 1898 there were 61 winding engines with an aggregate horse-power of 3161, 53 pumping-engines with a horse-power of 3891. There were employed 116,160 men, 6489 women, and 6036 lads. During the year there were ten fire-damp explosions, no miners being killed, but eight being severely and ten slightly injured.

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* *Colliery Guardian*, vol. lxxix. p. 1075.

† *Report of the Department of Mines*, Perth, 1900, p. 6.

‡ *Statistisches Jahrbuch des K.K. Ackerbau-Ministeriums*, Part II., 1899.

The Iron Industry of Austria.—C. R. von Ernst* considers generally the progress that has been made by the iron industry in the nineteenth century, and in particular the share that Austria has taken in it. The first half of the century is marked by the steady replacement of vegetable by mineral fuel in blast-furnace practice, and in the subsequent treatment of the metal; while in the second half the steady transition from the manufacture of weld iron to that of ingot metal is most marked, and steel has replaced iron. The impulse for each of these changes has come from the United Kingdom. In this country coal was generally employed in iron metallurgy at the commencement of the century, but in all other countries charcoal was in general use, and coke was only employed successfully in Upper Silesia. In the chief iron-producing districts of Austria the conditions were more unfavourable to the use of coal than anywhere else; but notwithstanding this, it came into use at a relatively early date. The largest Austrian furnace was at that time the Egger furnace at Treibach, in Carinthia; those at Rohnitz in Hungary, the Joseph furnace at Reschitza, and the Strimbul furnaces in Transylvania were the largest in Hungary. They varied in height from about 24 feet to 37·5 feet, while the maximum daily out-turn of such a furnace was about 6½ tons. The author compares this out-turn with an out-turn of 720 tons in one day stated to have been obtained at blast-furnace No. 3 of the Carnegie steelworks in July 1898. The first coke blast-furnace in Austria was erected in 1821 at the Sternberg works at Darowa in Bohemia, after experiments by A. Obersteiner had shown that Bohemian coal could be converted into suitable coke. Nine years later the first important coke oven plant was built at Witkowitz, and this really introduced the coke blast-furnace practice permanently into Austria. As the manufacture of coke spread, foundry practice underwent important changes.

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[*] *Zeitschrift des Oesterreichischen Ingenieur und Architekten-Vereines*, vol. lii. pp. 321–322.

Before this, most castings were made direct from the charcoal blast-furnaces, but these often made iron that was unfit for good castings. This led to the custom of re-melting the pig iron before making castings, mixing the more suitable varieties as was desired. The crucible furnace was used for this re-melting, as well as reverberatories, and, in particular, the shaft or cupola furnace. This latter had been first introduced and perfected in the United Kingdom. At this period the Wrbna foundries at Komorau and Horowic in Bohemia had a great reputation for castings. At first they used the iron direct from the blast-furnace, but in 1819 a hexagonal-shaped cupola was erected, about 8 feet in height, in which coke was used as fuel, and a somewhat smaller one in which charcoal was used. Coal was more rapidly introduced in the fineries and puddling furnaces than it was in blast-furnace practice, and here again it was the United Kingdom that took the lead. The author traces the use of coal, wood, peat, brown coal, and gas in the puddling furnace, and then passes to the utilisation of blast-furnace gases and the introduction of the closed-top blast-furnace, the use of steam blowing-engines, and the transition from cold to hot blast. Hot blast was first used in Austria in 1836 at the two blast-furnaces at Jenbach and Kiefer in the Tyrol, at Flachau and Dientent in the Salzburg district, and at the Eberstein ironworks. The introduction and use of the rolling-mill and other improvements in Austrian iron and steel practice are also traced. In conclusion, the author draws attention to the great progress that has been made in the present century in the scientific side of iron-smelting, its chemistry, and the physical and chemical properties of the metal produced.

The Witkowitz Collieries.—Very full details are given by M. von Gutmann* as to the workpeople employed at the Witkowitz collieries, their conditions of life, and the extra cost and diminished output due to the safety regulations now in force.

Brown Coal in Bohemia.—The production of brown coal in Northern Bohemia in 1899 amounted to 17,897,614 tons, an increase of 647,098 tons as compared with the output in the previous year. The workpeople employed numbered 31,508.†

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* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. pp. 161–169.

† *Ibid.*, p. 558; *Deutsche Kohlen-Zeitung*, 1900, p. 322.

Mineral Statistics of Hungary.—The production of Hungary in the year 1898 included the following, the figures for 1897 being also shown :*—

	1897.	1898.
	Metric Tons.	Metric Tons.
Brown coal	3,863.311	4,206 694
Coal	1,072,549	1,239,498
Briquettes	27,022	31,781
Coke	7,219	8,190
Forge pig iron	402,503	448,621
Foundry pig iron	17,398	20,784
Manganese ores	53	65

The accidents in the Hungarian mines and works were as follows in the year 1898:—Collieries, 22 fatal and 51 severe; brown coal mines, 28 fatal and 83 severe; iron ore mines, 17 fatal and 27 severe; ironworks, 2 fatal and 6 severe. The workpeople employed numbered 9581 in the collieries, 20,634 in the brown coal mines, 11,783 in the iron ore mines, and 6498 in the ironworks.†

Mineral Statistics of Bosnia and Herzegovina.—The official statistics for the year 1899 show the mineral production of Bosnia and Herzegovina to have included :‡—

	1899.	Increase or Decrease.
	Metric Tons.	Metric Tons.
Iron ore	67,085	+8,552
Chrome ore	196	− 262
Manganese ore	5,266	− 54
Pig iron	13,749	−1,587
Castings	1,109	+ 167
Open-hearth ingots	10.080	+1,410
Rolled iron	9,939	+1,428
Charcoal, cubic metres	105,700	−23,512

The reduction in the production of pig iron was due to a blast-furnace having undergone rebuilding during the year.

The quantity of brown coal mined during 1899 was 303,425 metric tons, this being an increase of 32,242 tons as compared with the production in 1898. At these brown coal mines 887 workpeople were employed in 1899, as compared with 777 in 1898. At the iron ore mines 235 workpeople were employed in 1899, an increase of 81, and at the ironworks 961, an increase of 230.

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* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. pp. 170–172.

† *Ibid.*, pp. 159–160.

‡ *Ibid.*, pp. 336–338.

The total number of workpeople employed at all the mines and smelting works numbered, in 1899, 5100, an increase of 30·7 per cent. as compared with the number of workpeople employed in the previous year. In the mines there were in 1899 three fatal and eight severe accidents, and at the works two severe accidents, but no fatal ones. In both fatal and severe accidents this represents a diminution of one as compared with the similar number for 1898.

IV.—*BELGIUM.*

Mineral Statistics.—The report published each year by E. Harzé [*] on the Belgian mineral statistics contains a mass of information regarding the coal and iron trades. The latest report shows that in 1899 the Belgian output of coal was 22,072,068 tons. The coke made amounted to 2,304,607 tons, valued at 20·5 francs a ton. There were 4276 coke ovens in operation. Of briquettes, 1,276,050 tons, valued at 16·05 francs a ton, were made at 37 works with 69 presses and 1191 workmen. The iron trade production comprised 1,024,576 tons of pig iron from 36 blast-furnaces, 475,198 tons of wrought iron, 731,249 tons of steel ingots, and 201,445 tons of iron ore.

The Belgian Government has issued the statistical year book [†] for 1900. It contains the final official mineral statistics for 1898. There were in that year in operation in Belgium 1521 quarries, employing 35,625 men, and raising mineral worth 52,799,930 francs. There were 114 collieries in operation, with a total output of 22,088,335 tons. They afforded employment to 122,846 persons. The production of the metal mines included :—

	Metric Tons.
Iron ore	217,370
Manganese ore	16,440

The metal mines afforded employment to 1679 workmen, the mean daily wage being 2s. (2·44 francs).

The report issued by Ernest de Jaer [‡] on the mining industry of Hainaut shows that the production of coal in the province last year amounted to 15,581,380 tons. The value per ton was 12·53 francs, and the profit per ton was 1·59 francs. The output per miner was 233 tons. The greatest depth attained was 3560 feet, at the Produits colliery. The production of coke was 1,670,620 tons, the number of coke ovens in operation being 2947.

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[*] *Annales des Mines de Belgique*, vol. v. p. 278.

[†] *Annuaire Statistique de Belgique*, vol. xxx.

[‡] *Moniteur des Intérêts Matériels*, vol. l. pp. 2269–2271.

Libert* has furnished the Belgian Government with his annual report on the coal-mining industry of the province of Namur. The coal output of the province in 1899 was 641,360 tons, an increase of 28,960 tons over that in 1898. The average depth of the workings is 313 yards. The deepest shaft is the Sainte-Eugenie pit of the Tamines colliery, which is 1771 feet deep. The collieries afforded employment to 3310 persons, of which 2371 were employed underground.

V.—*CANADA.*

Mineral Statistics.—The mineral statistics of the Dominion of Canada for 1899 † comprise:—

	Tons.
Iron ore	69,997
Chrome iron ore	1,796
Coal	4,142,242
Coke	91,463
Fireclay	543
Limestone for flux	48,265
Manganese ore	279
Nickel ore	2,605
Moulding sand	12,450

The production of crude petroleum was 808,570 barrels.

The Iron Industry.—The production of all kinds of pig iron,‡ including spiegeleisen and ferro-manganese, in 1899 in Canada, was 94,077 tons, of which 17,796 tons were charcoal pig iron. The production of steel ingots was 22,000 tons.

During the Canadian meeting of the American Institute of Mining Engineers, visits were paid to the Dominion Iron and Steel Company's Works in course of erection at Sydney, to the ore deposits at Belle Island, and to the collieries of the Dominion Coal Company, besides other works. The steel plant will draw its metal from four 350-ton furnaces and is intended to produce 1400 tons daily. A by-product coke oven plant to supply coke and illuminating gas is also in course of construction, and a second large steelworks is to be built by the Nova Scotia Steel Company at North Sydney. The estimated cost of the pig iron is given as approximately £1, 3s., made up of 7s. 6d. for 1·8 ton of ore, 7s. 6d. for 1·25 ton of coke, and 1s. 8d. for 0·75 ton of limestone, the remainder being absorbed by labour and other expenses.*

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* *Moniteur des Intérêts Matériels*, vol. l. pp. 1933–1934.

† *The Mineral Industry*, vol. viii. p. 824.

‡ *Annual Statistical Report of the American Iron and Steel Association*, Philadelphia, 1900, p. 70.

G. E. Drummond † briefly reviews the progress of the iron industry in Canada in 1899, and refers to the ore deposits and the new works.

Coal in Nova Scotia.—Coal-mining in Nova Scotia dates back more than a century, the first shipments reported being 1668 tons in 1785. For fifty years, however, the production was small. In 1835 the shipments had risen to 56,434 tons. From that time on, the increase was more rapid, and at the end of the second fifty years, in 1883, the shipments were 1,254,510 tons. In 1889 the production almost doubled that of 1885, amounting to 2,419,137 tons, and for the current year it will probably exceed 3,000,000 tons.‡

VI.—*CHILI.*

Coal.—Statistics have been published § of the production of coal in Chili during the past ten years. In 1890 the output was 194,675 tons, whilst in 1899 it amounted to 241,995 tons.

VII.—*FRANCE.*

Iron Trade Statistics.—Details ‖ are published of the French mineral production during the first half of this year. The output of fuel comprised 16,196,966 tons of coal and 332,921 tons of lignite. The production of iron and steel was as follows:—

	Metric Tons.
Forge pig iron	1,033,901
Foundry pig iron	253,140
Merchant iron	374,968
Iron plates	44,631
Steel rails	128,698
Merchant steel	345,148
Steel plates	155,373

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* *Engineering News*, vol. xliv. pp. 181–182, 186–188.

† *Journal of the Canadian Mining Institute*, vol. iii. pp. 118–123.

‡ *Canadian Mining Review*, vol. xix. p. 198.

§ *Revista de Minas* (Santiago), October 20, 1900.

‖ *Echo des Mines*, vol. xxvii. p. 1243.

The figures are practically the same as those for the corresponding period of last year.

The French imports and exports* during the first half of this year included :—

	Imports.	Exports.
	Metric Tons.	Metric Tons.
Coke	760,210	36,590
Iron ore	1,049,950	186,853
Pig iron	87,314	72,838
Wrought iron	27,411	16,963
Steel	12,785	9,763

Iron Ore.—Of the 5,000,000 tons of ore raised annually in France, 4,000,000 are obtained from the minette district, while of the 2·5 million tons of pig iron made, some 1·5 million is obtained from minette ores. The seams of ore reach to about 20 feet in thickness, with from 36 to 42 per cent. of iron. In places this percentage falls to as low as 27. New blast-furnaces are being erected near Nancy, Villerupt, and in the Upper Orme valley, and when these are finished this ore field will have 80 blast-furnaces. Bore-holes which have been put down have proved around Briey at least 2000 million tons of ore.†

The Paris Exhibition.—The Paris Exhibition, from April 15 to November 12, was visited by 50,859,935 persons, 47,076,803 tickets having been used. At the Exhibition of 1889 the number of tickets used was 28,149,352. The Exhibition naturally gave rise to the publication of a large amount of technical literature, to some of which reference has already been made in this volume. The metallurgical exhibits are described in H. Bauerman's paper and elsewhere.‡

Le Mois Scientifique et Industriel devotes a special section to abstracts of important memoirs dealing with the Paris Exhibition. One of the most interesting articles is that by G. Eude, dealing with the mechanical installations at the Exhibition. Motive power was produced in the form of electrical energy. The most powerful plant of French construction was that made by the Alsatian Company, which has an indicated horse-power of 1200 and a power of 675 kilowatts. The most powerful of the foreign plants was the Willans and Robinson steam-engine and the Siemens Brothers' dynamo, exhibited in the British Section, which had an indicated horse-power of 2400 and a power of 1340 kilowatts. The most powerful German plant was the Borsig engine and Siemens and Halske dynamo, with 2230 indicated horse-power and 1250 kilowatts.

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* *Comité des Forges, Bulletin*, No. 1637.

† *Stahl und Eisen*, vol. xx. p. 845.

‡ *Engineering News*, vol. xliv. pp. 48–49; *Ironmonger*, vol. xcii. July 7, 1900; *Iron and Coal Trades Review*, vol. lx. p. 1228; vol. lxi., Supplement, August 10, 1900.

The report of the Secretary of the British Iron Trade Association on iron and steel at the Paris Exhibition has appeared.* It contains sections on iron ore, pig iron, wrought iron, open-hearth and basic steel, railway material, steel plates and sheets, wire, pipes and tubes, castings, forgings, tin-plates, armour-plate, die steel, bolts, nuts, nails, transport, and other matters.

Mineral Statistics of Algeria.—The Governor-General of Algeria reports that in 1899 the Algerian mineral statistics included:—

Mines.	Number of Mines.	Number of Miners.	Value of Crude Product. Francs.
Iron ore (Constantine) . .	6	643	660,680
Coal (Algiers)	1	18	2,400

The exports of iron ore from the Beni-Saf iron mines in Algeria in 1899 were 26,224 tons more than in the previous year. They amounted to 393,143 tons, of which quantity 183,237 tons came to Great Britain.

VIII.—*GERMANY.*

Iron Trade Statistics.—The returns of the Imperial Statistical Bureau show that the production of the mines and works of Germany and Luxemburg in the year 1899 included the following:—

	Metric Tons.
Coal	101,639,753
Brown coal	34,204,666
Asphalt	74,770
Petroleum	27,027
Iron ore	17,989,635
Manganese ore	61,329
Pig iron	8,143,132

The production of pig iron in the German Empire, including Luxembourg, together with the imports and exports into and from Germany and Luxemburg, were as follows in 1899, according to the statistics collected by the *Verein deutscher Eisenhüttenleute* : *—

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* *Iron and Coal Trades Review*, vol. lxi. pp. 521, 629, 683.

	Metric Tons.
Production	8,029,305
Imports	675,793
Exports	235,194

The consumption of pig iron in Germany shows a steady increase since 1891, when it amounted to 4,720,242 tons. In 1899 the consumption was as much as 8,469,904 tons, while in 1884 it was only 3,599,106 tons. In 1894 and 1895 the exports of pig iron from Germany slightly exceeded the imports, but in every other year since 1887 the reverse had been the case.

The present position of the iron industry of Germany is discussed.† The progress made has of recent years been extremely rapid, but of late the enormous production in the United States and the troubles in China have greatly affected the position for the worse, and it seems possible that the iron trade of Germany may suffer seriously. How rapid has been the increase in the production is shown in tabular form. The first table shows the production, consumption, imports and exports of pig iron in the German Customs Union for each of the years 1891-1899. The annual percentage increase in production has been as follows, each year being compared with the preceding one: 6·4, 0·3, 12·2, 4·1, 9·9, 8·3, 7·5, and 8·4. For the years shown the details are as follows:—

Year.	Production.	Consumption.	Imports.	Exports.
	Metric Tons.	Metric Tons.	Metric Tons.	Metric Tons.
1891	4,641,217	4,720,242	244,256	111,154
1895	5,788,798	5,768,251	188,217	135,289
1899	8,029,305	8,469,904	612,652	182,091

In the first eight months of 1900 the production has been 5,469,014 tons as compared with 5,367,509 tons in the similar period of the previous year. This is an increase of 1·9 per cent. only, while simultaneously the imports of pig iron into Germany during these periods have risen from 383,223 tons in the first eight months of 1899 to 485,195 tons in 1900, and the exports have fallen from 125,461 tons to 82,549 tons. If the imports of pig iron should continue at the same rate, it would at the end of the year amount to about three-quarters of a million tons, a figure never before approached. It seems generally thought that the backward condition of the German blast-furnaces is due to the inadequate supply of furnace coke. There has now been a large increase made in the producing capacity of German coke oven plants, and it is believed that this will react very largely and favourably on the blast-furnace output. The imports of pig iron from the United Kingdom have very considerably increased of late.

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* *Stahl und Eisen*, vol. xx. p. 283.

† *Ibid.*, pp. 1029–1033.

The varieties of pig iron made in Germany have been as follows in the years mentioned :—

Year.	Production of Pig Iron.		
	Foundry.	Forge and Spiegeleisen.	Acid and Basic Bessemer.
	Metric Tons.	Metric Tons.	Metric Tons.
1891	739,948	1,553,835	2,337,199
1895	887,509	1,193,992	3,373,223
1899	1,424,732	1,663,571	4,941,002

The next table given is for this country an important one, showing as it does the sources from which the pig iron imported into Germany is derived, and the present great preponderance of the British imports. It is as follows :—

Year.	Imports of Pig Iron.				
	Total Imports.	From United Kingdom.	From United States.	From France.	From Sweden.
	Metric Tons.	Metric Tons.	Metric Tons.	Metric Tons.	Metric Tons.
1891 . .	244,256	217,133	...	6,044	5,998
1893 . .	218,998	191,643	...	14,542	6,267
1894 . .	203,948	182,056	1,503	8,028	5,368
1895 . .	188,217	160,504	3	13,245	7,885
1897 . .	423,127	362,007	18,034	21,911	13,036
1898 . .	384,561	308,883	20,849	40,345	10,476
1899 . .	612,652	529,770	29,661	34,432	10,940
First eight months of 1900 .	485,195	458,076	10,178	5,935	6,276

It will be noticed that the imports from the United States have been but small. It is pointed out, however, that it would be false to draw from these the deduction that the American iron trade exerts little real influence on the European iron trade, statistics being quoted which show how great has been the increase in the general iron trade exports of the United States during the first seven months of 1900 as compared with the similar period of 1899. Fourteen different kinds of iron and steel ingots, slabs, and manufactures are quoted. The total quantity of these which was exported from the United States in the first seven months of 1899 was 365,704 tons, and in the same period of 1900, 421,020 tons; the exports of steel rails included in these totals having been respectively 129,501 tons and 222,308 tons. The ocean freight charges from the United States to Germany are now about £1 per ton.

The production of basic ingot metal in Germany has been as follows:—

Year.	Converter.	Open-Hearth.	Totals.
	Metric Tons.	Metric Tons.	Metric Tons.
1894	2,342,161	899,111	3,241,272
1895	2,520,396	1,018,807	3,539,203
1897	3,234,214	1,304,423	4,538,637
1899	3,973,225	1,693,825	5,667,050

It will be seen that the percentage increase in out-turn has been very great, especially in the case of the open-hearth metal. In another table is shown the production of castings. In 1891 the castings made amounted to 1,050,217 tons, and in 1899 to 1,769,101 tons. The finished manufactures of weld iron and of ingot iron were respectively 1,411,653 tons and 1,841,063 tons in 1891, and 1,103,740 tons and 4,791,022 tons in 1899. The latter has therefore shown an enormous increase during this period, while the weld iron shows a considerable diminution.

The last table given relates to the German imports and exports of iron and iron wares, not including pig iron, scrap, or machines, the figures for each of the years 1891–1899 being given, and also a comparative statement for the first eight months of 1899 and 1900. These figures were as follows:—

Year.	Imports.	Exports.
	Metric Tons.	Metric Tons.
1891	76,485	1,034,808
1895	68,673	1,307,752
1897	103,658	1,263,963
1898	164,046	1,274,693

During the first eight months of 1899 and 1900 these figures were :—

Year.	Imports.	Exports.
	Metric Tons.	Metric Tons.
1899	102,298	969,571
1900	114,244	994,540

Coal.—The prevailing scarcity of coal continues to receive careful attention in Germany. C. Engel * makes an able reply to the attacks that have been made on the coal syndicate of Rhineland-Westphalia. He shows that the collieries of the Ruhr coalfield not included in the syndicate and those of the Aix-la-Chapelle field, although free from any restriction of output, have since 1892 only increased their production 30 and 25·5 per cent. respectively, whilst that of the syndicate has increased 50 per cent. The subject is also discussed elsewhere.† Statistics are given showing that in 1890 of the Prussian coal production 55·17 per cent. was from the Ruhr district, 9·65 per cent. from the Saar mines, and 26·21 per cent. from Upper Silesia. In 1889, on the other hand, the proportions were : Ruhr field, 57·50 per cent. ; Saar collieries, 9·52 per cent. ; and Upper Silesia, 24·82 per cent. The production of the Ruhr field in which the syndicate operates thus represents a greater percentage of the production of the kingdom than it did ten years ago.

The imports and exports of coal of the German Customs Union have been as follows in the years shown : ‡—

Year.	Imports.	Exports.
	Metric Tons.	Metric Tons.
1892	4,436,983	9,649,055
1893	4,664,048	9,677,305
1894	4,805,971	9,739,075
1895	5,117,356	10,360,838
1896	5,476,753	11,598,757
1897	6,072,030	12,389,907
1898	5,820,332	13,989,223
1899	6,220,489	13,943,174

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* *Glückauf*, vol. xxxvi. pp. 817–822.

† *Industrie*, September 30, 1900.

‡ *Stahl und Eisen*, vol. xx. p. 453.

The production of coal in Prussia has increased from 64,373,816 tons in 1890 to 94,778,252 tons in 1899, while the output of the Ruhr basin has increased from 35,517,083 tons to 54,494,000 tons during the same period, and that of the collieries belonging to the Rhenish-Westphalian syndicate from 33,539,230 tons in 1893 to 48,024,014 tons in 1899. The production of the Saar collieries was 6,212,540 tons in 1890, and that of the collieries of Upper Silesia in the same year 16,870,886 tons, the figures for 1899 being respectively 9,025,071 tons and 23,527,317 tons. Since 1892 the output of coal in each district has shown a steady increase year by year. A number of other details are also given.

As an introduction to the German mining exhibits at Paris, an excellent essay on the mining industry of Germany has been prepared by C. Engel.* A good idea of the importance of the industry is afforded by the sum paid as wages. In 1897, the last year for which exact and complete statistics are available, the insurance against accidents in mines and works included 455,417 undertakings and a total of 6,043,000 workmen, the wages being £212,681,030. The Miners' Association alone comprised 1838 mines and 459,000 workmen (7·7 per cent. of the total), whilst the wages represented 10·8 per cent. of the total. The seven Metallurgical Associations comprised 21,681 works and 675,000 workmen (11·2 per cent. of the total), whilst the wages represented 14·2 per cent. of the total. The growth of the mining industry is well shown by the following figures dealing with the Dortmund district:—

Year.	Number of Collieries.	Production. Thousands of Tons.	Number of Miners.
1792	154	177	1,357
1800	158	231	1,546
1830	172	571	4,457
1850	198	1,606	12,741
1870	220	11,813	51,391
1890	177	35,469	127,794
1898	168	51,002	191,846

Imports and Exports.—The imports and exports of the German Customs Union included the following in the year 1899: †—

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* German Official Catalogue.

† *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. p. 199.

	Imports.	Exports.
	Metric Tons.	Metric Tons.
Brown coal	8,616,751	20,925
Oils from peat, shale, and brown coal tar	93	88
Oils from coal-tar, light	5,292	2,755
,, ,, heavy	2,543	8,640
Graphite	23,399	2,703
Coke	462,577	2,137,985
Iron ore	4,165,372	3,119,878
Manganese ore	196,825	7,040
Cobalt and nickel ore	13,469	8
Chrome ore	14,915	112
Magnesite	11,733	3,119
Fireclay, kaolin, felspar	235,233	143,406
Firebricks	41,479	149,785
Basic slag	70,557	199,382
Ozokerite	9,115	3,620
Petroleum, unrefined	5,785	5
,, refined	897,175	1,093
,, other distillates	8,108	3,666

The pig iron and scrap imported amounted to 675,793 tons, and that exported to 235,193 tons. The similar figures for wrought iron were respectively 37,179 tons and 193,933 tons; for metallic nickel, 1391 tons and 295 tons; for tar, 39,696 tons and 30,678 tons; for explosives, 22 tons and 3248 tons; and for mineral lubricating oils, 106,624 tons and 2165 tons.

The imports and exports of the German Empire during the first half of 1900 included the following, the similar data for the first half of 1899 being also shown:*—

	Imports.		Exports.	
	First Half, 1899.	First Half, 1900.	First Half, 1899.	First Half, 1900.
	Metric Tons.	Metric Tons.	Metric Tons.	Metric Tons.
Iron ores	1,761,567	1,839,635	1,578,144	1,618,888
Iron slags and slag wool	384,801	522,977	13,432	16,232
Ground basic slag	33,270	49,577	51,675	44,983
Pig iron scrap and semi-manufactures	277,790	417,658	135,186	91,200
Manufactures such as shapes, rails, and sheets	34,092	42,929	447,137	451,594
Quite coarse manufactures	26,044	25,322	53,989	69,181
Coarse manufactures	10,762	13,696	114,728	111,509
Total manufactures	39,006	41,548	186,371	200,479
Total of all sorts of iron and steel manufactures and semi-manufactures	415,083	583,757	892,806	879,184

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* *Stahl und Eisen*, vol. xx. pp. 913–914.

The total value of these iron and steel imports, excluding iron ores, was £4,350,300 in the first half of 1899, and £5,768,000 in the first half of 1900, while the values of the similar exports were for these periods respectively £16,481,950 and £18,022,100.

Iron Trade Statistics of Upper Silesia.—In the year 1899,* there were in Upper Silesia 59 collieries provided with 1086 steam-engines of 102,122 horse-power, the similar figures for 1898 having been respectively 55, 1035, and 91,807. The workpeople employed numbered 63,115, or 6·2 per cent. more than in the previous year. Of this number 3783 were females. The average wages earned during 1899 per workman over sixteen was £45, 16s., and under sixteen, £13, 17s. A woman earned on the average £14, 10s. The production of coal was 23,527,317 metric tons, an increase of 1,025,118 tons, or 4·6 per cent. as compared with the production in the previous year. The iron ore mines numbered 43, an increase of one on the year. The workpeople employed numbered 2982, an increase of 96, and the production amounted to 435,110 tons, this representing an increase on the year of 4·0 per cent. The average quantity of coal wound per workman was 372·8 tons, and of iron ore 140·57 tons. The production of coal was as follows in those parts of the Silesian coal basin which are not parts of the German Empire:—

District.	Production.	Increase.
	Metric Tons.	Metric Tons.
Moravian Ostrau . . .	6,252,163	295,305
Jaworzno	869,320	97,095
Russian Poland	3,904,996	17,709
Add for Upper Silesia proper .	23,527,317	1,025,118
Total for the whole basin . .	34,553,796	1,435,227

The coke blast-furnaces in Upper Silesia proper numbered 40, an increase of three. Of these, 34 were in blast, this being an increase of two. The workpeople employed numbered 4588, an increase of 570, and 744,466 tons of pig iron were produced, an increase of 9·7 per cent. on the year. While the production of forge pig iron diminished by 3 per cent. of the total production, that of basic pig iron has risen 16·7 per cent. The exports of pig iron to Austria-Hungary amounted to only 700 tons, or 520 tons less than in the preceding year. A workman over sixteen averaged a wage for 1899 amounting to about £46, 10s.

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* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. pp. 326–329.

A boy earned £18, 5s. There was only one charcoal blast-furnace at work. This was in blast for 21 weeks. The pig iron made sold for £6, 15s. per ton.

There were at work in 1899 26 iron-foundries, provided with 44 cupolas, 13 reverberatories, 8 open-hearths, and 2 annealing furnaces. The workpeople employed numbered 3263, an increase of 15·1 per cent. as compared with the numbers employed in 1898. The production of castings amounted to 90,884 tons, an increase of 19 per cent. Of this quantity 18,814 tons were pipes.

At 21 ironworks there were 277 puddling furnaces and 232 other furnaces, together with 87 steam-hammers and 64 presses. In addition there were 8 cupolas, 2 cast-steel furnaces, 2 acid and 6 basic Bessemer converters, and 95 rolling-mills. The steam-engines in use numbered 440 with 36,214 horse-power. The workpeople employed numbered 19,249, an increase of 3·8 per cent. Of these 805 were females. The average earnings of a workman over sixteen were £49, 12s.

At five works making wire, wire-rod, nails, chains, and pipes, 3918 workpeople were employed. The production amounted to 71,601 tons as compared with 66,744 tons in 1898, the average value per ton was £13, as compared with £11, 12s. in 1898. At two fineries 14 workpeople were engaged, and the production amounted to 214 tons.

The coke oven plants numbered 14. These employed 4071 workpeople, and made 1,212,149 tons of lump coke, 85,620 tons of smalls, and 101,276 tons of cinder. The by-products amounted to 116,571 tons, and the total value of all the coke oven products to £1,078,679. The consumption of coal increased by 2·1 per cent., but the production of coke increased by 3·8 per cent., and the value of the various products by 9·8 per cent.

Mineral Statistics of the Siegen District.—The Mining and Smelting Association of Siegen reports the output of the iron ore mines and ironworks to have been as follows in the years mentioned: *—

	1898.	1899.
	Metric Tons.	Metric Tons.
Iron ores	1,640,877	1,800,980
Nickel ores	...	16
Coke pig iron	491,110	570,890
Charcoal pig iron	1,264	851
Iron and steel	284,524	315,089
Castings	43,676	52,924
Various manufactures	10,884	13,095

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* *Stahl und Eisen*, vol. xx. p. 1018.

The output of the blast-furnaces shows an increase of 16 per cent. on the year. Eighteen per cent. of this total output was subject to further treatment within the district, while 65 per cent. went to other parts of Germany, and 17 per cent. to foreign countries.

The Iron Industry of Lorraine.—It is proposed to canalise the river Moselle from Metz to Coblentz, and Heidegger,* in describing the proposal, shows how it would advantage the iron industry of Lorraine. In 1885 there were in Lorraine some 18 blast-furnaces, using about 500,000 tons of coke a year. Now there are about 45 furnaces, and the annual consumption of coke is far more than three times as much as it then was. The production of iron ore in Lorraine was as follows in 1899:—

	Metric Tons.
Smelted in Lorraine	3,739,536
Sent by railway to the Saar	1,348,804
Sent to Westphalia and the Rhine district	701,665
Sent to Luxembourg	550,306
Sent to France	477,696
Sent to Belgium	154,683
Total	6,972,690

The production of iron at the Lorraine blast-furnaces amounted to:—

Pig iron	1,290,164
Weld iron	70,324
Ingot iron	234,938
Foundry products	17,946

In addition there were also exported from Lorraine 72,330 tons of semi-manufactures, steel billets, &c. The workpeople employed in the mines and smelting works of Lorraine in 1899 numbered over 22,500, these being distributed as follows:—

	Number.
Mines	8,638
Blast-furnace plants	7,568
Weld and ingot ironworks	5,929
Foundries	400
Total	22,535

There were also employed at various other works in Lorraine 4248 workpeople. These works included those making ground basic slag and slag bricks, of which considerable quantities are now being made.

The author deals at much length with the question of the commercial advantages which would be derived from this canalisation of the Moselle, and with the cost and other details of the scheme.

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* *Stahl und Eisen*, vol. xx. pp. 805-814.

Mineral Statistics of Prussia.—The Prussian mineral statistics for 1899 have been published.* The details given include the following:—

	Number of Mines.	Output.	Number of Miners.
		Tons.	
Coal	274	94,740,829	343,413
Brown coal	397	28,418,598	37,017
Asphalt	3	16,458	42
Petroleum	6	3,405	124
Iron ore	486	4,295,575	23,817
Manganese ore . . .	23	60,379	377

Preliminary returns show † that during the first half of this year Prussia produced 49,630,982 tons of coal. There were 270 collieries in operation and 364,980 workmen employed. The production of brown coal was 16,025,246 tons. There were 385 brown coal mines in operation and 40,500 workmen employed.

The accident returns show that the proportion of fatal accidents per 1000 miners employed was in Prussia, in 1899, as follows:—

	Per Cent.
Coal-mining	2·518
Brown coal mining	1·946
Ore mining	1·079
Mining of other minerals	1·708
Mining generally	2·204

Altogether there were during the year 48 fire-damp explosions, 36 of which caused fatal accidents.

Mineral Statistics of Bavaria.—The official mineral statistics ‡ of Bavaria for 1899 show that the production included:—

	Mines.	Tons.	Miners.
Coal	15	1,004,420	6265
Brown coal	8	35,736	158
Iron ore	35	181,980	722

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* *Zeitschrift für das Berg-, Hütten- und Salinenwesen im preussischen Staate*, vol. xlviii. pp. 1–65.

† *Glückauf*, vol. xxxvi. p. 664.

‡ *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. p. 351.

There was also produced :—

	Tons.
Graphite	5,196
Petroleum	68
Ochre	9,287
Fireclay	271,792

The Bavarian metallurgical production in 1899 comprised :—

	Tons.
Pig iron	83,821
Cast iron	92,458
Bar iron	61,414
Iron wire	111
Steel	134,007

The Krupp Steelworks.—An account is published * of the Krupp Steelworks at Essen. The Krupp Company owns steelworks at Essen, at Annen on the Weser, at Buckau near Magdeburg; four blast-furnace plants at Duisburg, Neuwied, Engers, and Rheinhausen; a smelting works and machine shops near Sayn; four collieries; over 500 iron ore mines in Germany, of which 11 are deep mines with complete winding and general plants; various iron ore mines near Bilbao; a gun-proving ground some 10 miles in length near Meppen, and with the possibility of increasing the range to about 15 miles; three ocean-going steamships, quarries, claypits, sandpits, &c. It also works the shipbuilding and machine construction works of the Germania Company at Berlin and Kiel. The cast-steel works at Essen are chiefly employed in gun construction. Down to the end of 1899, 38,478 guns had been constructed at this works, which has in operation two Bessemer plants provided with 15 converters, four open-hearth plants, and numerous other furnaces and shops. Altogether some 1700 different furnaces, smith's fires, &c., were in operation at this works in 1899, together with 4000 different machines and 132 steam-hammers, varying from 0·1 ton to 50 tons falling weight, their total falling weight being 269 tons. There were also in use over 30 hydraulic presses, two of which were each of 5000 tons power, one of 2000, and one of 1200 power. The total horse-power of the various steam-engines used was 41,213, and there were in use 558 cranes with a total carrying power of 5963 tons. The total quantity of coal and coke consumed by the Krupp Company during the year by all its works, steamers, &c., was 1,570,483 tons. The Rheinhausen blast-furnace plant possesses three blast-furnaces, each of which produces on the average 230 tons of pig iron in twenty-four hours. A number of other interesting details are given. Then it is stated that the gas-producing plant at the Essen steelworks occupies the seventh position for size in the whole of Germany, while the quantity of water used at this works was about as much as was used by the city of Frankfort-on-the-Main. At the testing laboratories of the Essen works 87,626 tensile, 83,262 bending, and 2321 other mechanical tests were made during the year in question.

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* Annual Report of the Essen Chamber of Commerce; *Stahl und Eisen*, vol. xx. p. 926.

The Ilsede Ironworks.—There were three furnaces in blast at the Ilsede Works in 1899.* These produced in 1095 working days 223,421 tons of metal, or about 204 tons a day. The ore and slag charged amounted to 643,663 tons, the yield of iron being thus 34·7 per cent. The coke charged was 219,835 tons, or 0·984 ton per ton of iron produced. No limestone was used. The actual cost of production of the pig iron was 36·3 shillings (marks) per metric ton. The furnaces are being renovated one by one, and the oldest blowing engine is being replaced by one of modern type, while a gas-engine plant is being erected for the purpose of the direct utilisation of the waste blast-furnace gases. These are to be employed for running dynamos, the electric power resulting being then available for the works and adjacent mines. Details are also given as to the output of the Peine rolling-mills.

Shipbuilding in Germany.—O. Flamm† discusses the shipbuilding industry of Germany, tracing its rise, and showing how rapid has been its progress. In the years 1897 and 1899 the number and tonnage of merchant vessels built in Germany was as stated :—

Year.	Number.	Tonnage.
1897	74	153,000
1899	174	440,000

In the years 1898 and 1899 taken together the merchant ships were engined to the extent of 349,247 horse-power. In 1899 the quantity of ship construction material worked in German yards was 85,500 tons for merchant vessels alone. The various larger shipbuilding works are briefly referred to statistically, and the kind of material used is shown by aid of a number of illustrations showing the result of various collisions, &c. The larger steamship companies are also briefly mentioned. It is incidentally pointed out that the *Kaiser Wilhelm der Grosse* consumes 3000 tons of coal in a single passage between Europe and America.

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* *Stahl und Eisen*, vol. xx. p. 716.

† *Ibid.*, pp. 457–465, with seven illustrations.

Iron Ore in Luxemburg.—Although the Grand Duchy of Luxemburg is small, it possesses great riches in iron ores of excellent quality. The growth of the mining industry is well shown by figures given by T. Kellen.* In 1870 the output of iron ore was 911,700 tons, whilst last year it was 6,014,400 tons, valued at £649,500. The oolitic iron ore, known as minette, extends over a zone 10 to 15 miles in width and 60 miles in length from Luxemburg over German Lorraine into French Lorraine. The percentage of iron varies from 30 to 40.

IX.—*INDIA.*

Mineral Statistics.—The statistics of the mineral production of India have been issued. The coal industry has expanded without a break from 2,168,500 tons in 1890 to 4,937,000 tons in 1899, a growth of 128 per cent. Coal of varying quality is found over a very extensive area in India. Of the yield last year about 79 per cent. came from Bengal, which contains important mines in the Raniganj district. The Nizam's territory, Assam, Central India, and the Central Provinces are at present the only other coal centres of note. For railways, steamers, mills, and factories Indian coal is extensively and increasingly used, and would be used still more widely but for the difficulties and expense of inland transport. Bombay, which requires large quantities of coal for its mills, is too remote from the chief mines to obtain the fuel economically, especially as British steamers carry coal thither under easy conditions as to freights. Hence the recent rise in coal imports into India in spite of increased production. In 1899–1900 422,000 tons were imported, of which Bombay Presidency (including Sind) took 369,000 tons; on the other hand, India exported 304,500 tons of her own coal from Bengal, Ceylon with 181,500 tons and the Straits Settlements with 87,000 tons being the chief purchasers.

Out of a total Indian production of 33,000,000 gallons of petroleum in 1899, 32,300,000 gallons came from the wells of Burma and 623,000 from those of Assam. The output in Burma rose steadily from 3,800,000 gallons in 1890 to 18,420,000 in 1898; but in 1899 there was a sudden expansion to the extent of 75 per cent. beyond the yield of 1898. The exportation of Indian mineral oil is increasing, 1,272,000 gallons being shipped to the Straits Settlements in 1899–1900. Demands for exportation, as well as for fuel for the furnaces of steamers in the Indian Ocean, may be expected to develop. India, however, requires far more oil than she can produce, and in 1899–1900 she imported nearly 75,000,000 gallons. The iron industry of India is in its infancy, the production in 1899 being roughly estimated at only 60,700 tons, of which 52,000 tons were produced in the Raniganj district of Bengal, in close proximity to the coalfields. Of manganese ore, increasing quantities are shipped to England from Madras.

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* *Der Gnom*, September 8, 1900.

X.—*ITALY.*

Mineral Statistics.—The mineral production of Italy in the years 1898 and 1899 included the following :*—

	1899.		1898.	
	Number of Mines.	Production.	Number of Mines.	Production.
		Metric Tons.		Metric Tons.
Iron ore	28	236,549	20	190,110
Manganese ore	7	4,356	7	3,002
Manganiferous iron ore	1	29,874	1	11,150
Nickel ores	1	3	...	...
Coal	30	388,534	28	341,327
Graphite	16	9,990	15	6,435

The imports and exports in 1899 included :—

	Imports.	Exports.
	Metric Tons.	Metric Tons.
Iron ores	20,799	234,215
Coal	4,859,556	20,803
Graphite	608	8,114

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* *Rassegna Mineraria*, vol. xiii. p. 100.

At the Paris Exhibition the Italian Department of Mines showed a well-arranged and carefully selected typical collection of Italian minerals, geological maps and mine plans. The educational value of this collection was greatly enhanced by the catalogue,* covering 261 closely printed pages. It contains details of the Italian mining and metallurgical industries which render it a treatise of permanent value. The collection is the most complete representation of the mineral resources of Italy ever got together, the number of specimens amounting to 1053. The catalogue of these covers nearly fifty pages. The following 110 pages are devoted to descriptions of the principal Italian deposits of economic importance. The third section, twenty-six pages, is devoted to descriptions of the metallurgical and chemical industries. The fourth section contains the Italian mineral statistics for the years 1860 to 1899, whilst the last section gives details of the constitution of the Department of Mines.

Tonietti † has prepared a report on the iron ore mines of Elba.

XI.—*JAPAN.*

Industrial Development.—B. H. Thwaite ‡ gives a detailed description of the new Japanese Government iron and steel works.

The length of the railways in Japan was only 18 miles in the year 1872–73. In the years 1898–1899 the length was as much as 3430 miles.§

XII.—*RUSSIA.*

Iron Trade Statistics.—The Russian Bureau of Statistics has published the iron trade returns for 1899. The production of pig iron amounted to 163,115,811 poods, or 21·6 per cent. more than in 1898. The production of wrought iron was 34,553,916 poods, and that of steel 80,667,140 poods. The production of petroleum increased from 69,918,325 poods in 1898 to 80,667,140 poods in 1899.

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* "Catalogo della mostra fatta dal Corpo Reale delle Miniere all' Esposizone universale del 1900 a Parigi," 1900 (Rome: Ministero di Agricoltura).

† *Iron and Steel Trades Journal*, vol. lxvi. p. 588; *Iron and Coal Trades Review*, vol. lxi. p. 14.

‡ *Indian and Eastern Engineer*, March 1900.

§ *Japan Weekly Mail; Stahl und Eisen*, vol. xx. p. 614.

Coal.—An account has been published* of the scarcity of coal in Russia; the lowering of the customs duties, and ways and means to increase the home supply are discussed, and tables showing imports in recent years are appended.

Despite the increased demand, the production of coal in the Dombrova basin not only showed no advance in 1899 as compared with the production in 1898, but even showed a diminution of 2·9 per cent. In 1898 the production was 249,667,760 poods, and in 1899 242,488,012 poods.†

The coal-mining industry of the Ural does not appear to make rapid progress. Statistics published in a St. Petersburg paper show that the output was as follows:—

Year.	Poods.
1890	15,200,000
1895	15,700,000
1896	20,000,000
1897	22,600,000
1898	20,100,000
1899	22,000,000

Petroleum.—Russia's production of petroleum in 1899 was the greatest ever known. The revenue derived from the excise duty on refined petroleum amounted to £2,800,000. The prosperous condition of the industry is to be attributed to the influx of British capital.

The oil fields of Baku ‡ in 1899 yielded 52,519,739 barrels of petroleum, as compared with 48,596,853 barrels in 1898. The exports of petroleum products of all kinds were as follows:—

	1898.	1899.
	Barrels.	Barrels.
Illuminating oil	10,515,777	11,463,344
Lubricating oil	1,042,100	1,270,666
Other products	145,000	123,000
Residues	24,236,100	24,485,600
Crude petroleum	4,389,200	14,891,410

The production of crude oil in Russia § in the first half of 1900 amounted to 276,000,000 poods, as compared with 266,000,000 poods in the first half of 1899. Of the former quantity, 27,000,000 poods were yielded by spouting wells, as compared with 59,000,000 poods from spouting wells in the first half of 1899. The total number of producers engaged in the oil industry is now 135, as compared with 114 in the same period of 1899, whilst the bore-holes numbered 1497 in 1900 as compared with 1197 in the previous year. The average yield per bore-hole was 185,000 poods in the first half of 1900, as compared with 220,000 poods in 1899. The exports of oil in the first half of 1900 amounted to 209,000,000 poods, as compared with 200,000,000 poods in the similar period of the previous year.

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* *Moniteur Industriel*, April 14, 1900.

† *St. Petersburger Zeitung; Stahl und Eisen*, vol. xx. p. 448.

‡ *Glückauf*, vol. xxxvi. p. 622.

§ *Petroleum Review*, vol. iii. p. 208.

Attention is directed* to the increase in the consumption of petroleum on the Russian railways. In 1885 they consumed 5,788,000 poods of petroleum residues; in 1890 the consumption amounted to 17,654,000 poods, and in 1896 it had reached 62,569,000 poods.

Manganese Ore.—The exports of manganese ore from Poti in 1899 amounted to 411,197 metric tons. Of this quantity 118,049 tons were sent to the United Kingdom.†

Mineral Industry of Siberia.—An exhaustive report on the mineral resources of Siberia has been published by E. Glasser,‡ a French mining engineer. Siberia possesses, he shows, important mineral deposits. There are, too, some fine deposits of iron ore and coal. Half the vast area of Siberia has not yet been explored.

The Siberian railway is tending to open up the country considerably, and various machine-shops and foundries have recently been started there.§

XIII.—*SPAIN.*

The Iron Industry.—A recent Foreign Office report gives much statistical information as to the production of ore in Spain. The iron ore mined in 1899 amounted to 9,344,320 tons, as compared with 7,197,045 tons in 1898. The share of the Bilbao district for these two years was 7,568,085 and 5,850,085 tons respectively. The number of kilns in that district was 33, employed in producing 613,575 tons of roasted spathic ore. Full details are given.

A report of the general meeting of the Viscaya Company of Bilbao ‖ has been published. The year 1899 was one of marked prosperity, the dividend paid being 8·22 per cent. The Robert converter has been replaced by the Tropenas process. The works produced last year 103,840 tons of pig iron, 20,414 tons of open-hearth steel, 20,788 tons of Tropenas steel, and 35,549 tons of rolled steel. All the coke required was made at the works, the output being 95,645 tons of by-product coke.

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* *Revue Scientifique*, July 21, 1900.

† *Stahl und Eisen*, vol. xx. p. 614.

‡ *Annales des Mines*, vol. xviii. pp. 5–78.

§ *Stahl und Eisen*, vol. xx. pp. 714–715.

‖ *Revista Minera*, vol. li. pp. 232–233.

The official mineral statistics of Spain for 1899 have been published by the Minister of Agriculture and Trade. The number of workmen employed was 69,858 in the mines and 18,958 in the works. The mining and metallurgical products represented a value of 343,000,000 pesetas.

Imports and Exports.—The Spanish imports* and exports during the first half of 1900 included:—

IMPORTS.	Metric Tons.
Coal	854,602
Coke	108,981
Pig iron	2,232
Wrought iron	3,046
Steel	28,697
Tin-plate	1,395
EXPORTS.	
Iron ore	4,073,673
Pig iron	14,572

Manganese Ore.—During the half-year ended June 30, 1900, the exports of manganese ore from the province of Huelva amounted to 79,230 tons, of which 2221 tons went to France and 77,009 tons to Belgium and Luxemburg.

XIV.—*SWEDEN AND NORWAY.*

Iron Trade Statistics.—According to the official statistics which have been issued by R. Åkerman, the director-general of the Board of Trade,† the production in Sweden in 1899 was:—

	Metric Tons.
Iron ores	2,435,200
Pig iron, &c., made with charcoal	497,727
Blooms produced from pig iron in charcoal hearths	195,331
Bessemer ingots and castings	91,898
Open-hearth ingots and castings	179,357

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* *Revista Minera*, vol. li. p. 375.

† *Kommerskollegii underdaniga berättelse*,.

	Metric Tons.
Crucible ingots and castings	1,225
Blister steel	974
Bar iron and steel	116,506
Nail and wire rod, hoop iron and steel	103,604
Otherwise shaped iron and steel in bars	10,051
Plates (not including sheets)	19,688
Tube blocks, hollow blooms, and billets	19,201
Coal	239,344
Number of blast-furnaces in blast	141
Average daily product per furnace	13·43
Average time per furnace in blast	263 days

The total number of active iron ore mines in Sweden in 1899 was 321, as compared with 329 in 1898. The production of iron ore, on the other hand, rose from 2,302,516 tons in 1898 to 2,434,606 tons in 1899. The workpeople employed numbered 3946 below ground, and 4791 at grass. The chief ore-producing districts were:—

	Production.	
	1899.	1898.
	Metric Tons.	Metric Tons.
Norrbotten	957,300	867,049
Kopparberg	771,140	751,038
Orebro	299,566	299,934
Westmanland	218,589	185,155

The total weight broken in 1899 was 3,991,638 tons, from which 2,420,160 tons of ore was obtained by separation. Of the ore obtained by deep mining, 2,165,156 tons, or 88·9 per cent., was magnetite, and 269,450 tons hæmatite.

The total number of blast-furnaces in operation in 1899 numbered 167 at 118 works, as compared with 171 at 120 works in 1898. Of these 141 were in blast for 37,031 days in 1899, and 143 for 39,847 days in 1898. The production was as follows:—

	1899.	1898.
	Metric Tons.	Metric Tons.
Direct castings	8,496	7,806
Forge pig iron	248,817	259,971
Bessemer and open-hearth pig iron	218,797	240,781
Total pig iron, including above	497,727	531,766

The production shows a diminution of 6·1 per cent. on the year as regards quantity, but its average value increased.

The works making malleable iron and steel in 1899 numbered 122, a diminution of four on the year. They possessed 341 hearths, 4 puddling furnaces, 27 Bessemer converters, 47 open-hearths (an increase of two), and 6 crucible steel furnaces. The total quantity of semi-manufactures (unrolled) amounted to 468,785 tons in 1899 and 464,044 tons in 1898. The value shows, however, a considerable increase. The rolled products included—

	1899.	1898.
	Metric Tons.	Metric Tons.
Bessemer metal	91,898	102,254
Open-hearth metal . . .	179,357	160,706
Crucible metal	1,225	1,013

The basic metal made, included in the above totals, amounted to 28,933 tons of Bessemer metal, 57,255 tons of open-hearth ingots, and 757 tons of open-hearth castings. The quantity of weld iron and steel rolled or hammered amounted to 364,467 tons in 1899 and 330,193 tons in 1898. The percentage of weld iron included in these totals was 43·21 in 1899 and 47·11 in 1898. The hammered material amounted in 1899 to 23·6 per cent. of the total, and that rolled to 76·4 per cent., the figures for 1898 being respectively 25·0 and 75·0.

Much discussion appears to have taken place recently in Sweden concerning the question of the supply and use of fuel, and of this a summary has recently appeared.*

Iron Ore.—G. Nordenström † deals fully with the iron ore deposits of Sweden. Statistics are given for each of 43 iron ore fields, giving their name and position, area, output of ore in 1897, tons of ore raised in 1897 per unit of area, and greatest depth of workings in 1895. The total area of ore shown is 388 acres, but this relates only to ore beds that are actually being worked. It is shown that the iron ore production of Sweden is capable of a large annual increase.

The Oldest Association of Ironmasters.—Bennett H. Brough ‡ traces the history of the Jernkontor, the Association of Swedish Ironmasters, the oldest institution of the kind, from its foundation in 1748.

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* *Engineer*, vol. xc. pp. 205–206.

† *Jernkontorets Annaler*, vol. liv. pp. 211–256.

‡ *Cassier's Magazine*, vol. xviii. pp. 1–9.

The paper is illustrated by portraits of Baron Tamm, R. Åkerman, and J. C. Kjellberg. There are also photographic views of the exterior, of the reception-room, and of the meeting-room of the Jernkontor on the occasion of the visit of the Iron and Steel Institute, with drawings of the official uniform of Swedish ironmasters, of the medal awarded to Pehr Lagerhjelm in 1856, of that struck in honour of Gustaf Ekman in 1877, and of the frieze of the Jernkontor building.

The Iron Industry of Norway.—The exports of iron ore from Norway have been as follows:—

Year.	Metric Tons.
1897	4242
1898	4601
1899	over 12,000

Of the exports in 1899, which amounted to rather more than 12,000 tons, 9600 tons were from the Fens mines near Ulefos. These mines are now being put into operation again after having been shut down for a lengthened period. From Soggendal iron ores are exported that contain 40 per cent. of titanic acid. The Näs crucible steelworks gave employment during 1899 to a hundred workpeople, and was in full operation during the year. No nickel works were at work during 1899, but an important discovery of nickel ore was made near Fäo on the west coast. The ore is a magnetic pyrites containing some 2 per cent. of nickel and 2·5 of copper in its assorted condition. The lode is 5 or 6 yards wide. The total number of workpeople employed at all the mines and metallurgical works in Norway in 1899 was about 2650, of which 2250 were at copper-mines or copperworks, the value of the products being 4,900,000 crowns.*

J. H. L. Vogt † of Christiania urges the possibility of creating an iron industry in Norway.

According to the Norwegian *Veritas*, there were forty-seven ships under construction in Norway on July 1, 1900. Of these forty-four were steamers of 37,920 tonnage, thirty-seven of these being of steel, their tonnage being 33,700. Only three small sailing ships were being built, their total net tonnage being only 510.‡

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* *Oesterreichische Zeitschrift für Berg- und Hüttenwesen*, vol. xlviii. p. 200.

† *Centralblatt der Walzwerke*, July 28, 1900.

‡ *Stahl und Eisen*, vol. xx. p. 1067.

XV.—*TURKEY.*

Imports.—The importation of steel into Turkey, according to customs statistics,* was as follows:—

Year.	Quantity.	Value.
	Tons.	£
1892-93	1305	22,236
1893-94	1613	26,371
1894-95	1543	16,531
1895-96	1224	15,426

The annual consumption of steel in Constantinople is estimated at 400 tons. Austria and England furnish almost all the steel used.

XVI.—*UNITED STATES.*

Iron Trade Statistics.—According to the returns of the American Iron Trade Association,† the production of pig iron in the United States during the first half-year of 1900 was 7,642,569 tons. Complete iron trade statistics for 1899 have been published.‡

Mineral Statistics.—The mineral production of the United States in 1899 is estimated§ to have included:—

	Tons.
Iron ore	25,341,000
Manganese ore	143,256
Bauxite	36,813
Chrome ore	100
Limestone flux	6,707,435

The production of petroleum was 57,234,304 barrels.

C. D. Walcott ‖ discusses the work of the United States Geological Survey in relation to the mineral resources of the United States.

Iron Ore.—John Birkinbine's report ¶ to the United States Government shows that the production of iron ore in the United States in 1899 was 24,683,173 tons, or 27 per cent. in excess of the previous maximum of 19,433,716 tons in 1898.

The production of manganese ore in 1899 was 9935 tons.

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* *Der Gnom*, October 1900.

† *Bulletin*, vol. xxxiv. p. 132.

‡ *United States Geological Survey, Twenty-first Annual Report.*

§ *The Mineral Industry*, vol. viii. pp. 5-10.

‖ *Transactions of the American Institute of Mining Engineers*, February 1900.

¶ *United States Geological Survey, Twenty-first Annual Report.*

Coal.—D. Bellet * has published an important article on the part of the United States in the world's coal production.

Tables of production † show that in 1899 the United States surpassed Great Britain for the first time in the production of coal.

Cost of Production.—F. Lürmann, jun., ‡ gives a number of details as to the cost of production of basic pig iron and basic steel in the United States. The first relates to a monthly out-turn of 10,282 tons, and the latter to a monthly production of 9668 tons. This latter is stated to be the actual cost for the year 1897. The total cost of the metric ton of pig iron is placed at about £2, 5s., and of the ton of basic ingots about £3, 12s. In the latter case, however, allowance has to be made for the basic slag and scrap. This reduces the actual cost to rather over £3, 7s. per ton.

James A. Green § discusses the past and future of pig iron. After pointing out that the United States produce the greatest amount of pig iron in the world, he declares that, in order to profit by this great advantage, Americans should turn out the most perfect manufactures of pig iron.

George H. Hull ‖ discusses industrial depressions and the pig iron reserve. He points out the difference between a panic caused by low prices and a depression caused by high prices, and presents statistics showing a close connection between abnormal prices for iron as well as reasons for great depression. He proposes a reduction of iron prices and the creation of a reserve supply as efficient means for recovering stability.

Shipbuilding.—At January 1, 1900, there were 109 steel steamers under construction or arranged for at the wharves on the Atlantic and Pacific coasts. These will have a total of 322,413 tons displacement, and consist of 59 trading steamers of 182,100 tons and 50 war vessels of 140,313 tons. In addition, Congress has arranged for six other war vessels of 76,500 tons displacement. Ten only of the new trading steamers are intended for foreign trade.¶

Some interesting statistics regarding the traffic on the American great lakes are given. ** The Sault-Sainte-Marie, joining Lake Superior to Lake Huron, is the busiest canal in the world. In 1869 the number of vessels that passed through was 1338, representing a tonnage of 524,881 tons. In 1889 the number of vessels was 20,255, and the tonnage 21,958,000 tons. The growth of the mineral traffic is shown by the following comparative statistics:—

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* *Moniteur des Intérêts Matériels*, vol. l. p. 3137.

† *Engineering and Mining Journal*, vol. lxix. pp. 644–645.

‡ *Stahl und Eisen*, vol. xx. p. 738.

§ *Iron and Steel Trades Journal*, vol. lxvi. pp. 519–520.

‖ *The Engineering Magazine*, vol. xix. pp. 641–654.

¶ *Stahl und Eisen*, vol. xx. pp. 715–716.

** *Revue Scientifique*, July 14, 1900.

	1879.	1889.	1899.
	Tons.	Tons.	Tons.
Iron ore	540,000	4,096,000	15,328,600
Coal	111,000	1,629,000	3,941,000

XVII.—*COMPARATIVE TABLES.*

The World's Production of Coal and Iron.—For purposes of comparison, the following summary of the production of coal in the principal countries of the world is appended:—

Country.	Year.	Production in Tons,
United Kingdom	1899	220,094,781
Australasia—		
New South Wales	1899	4,597,028
New Zealand	1899	975,234
Queensland	1899	494,000
Tasmania	1899	42,000
Victoria	1899	262,380
West Australia	1899	54,000
Austria, coal	1898	10,947,521
,, lignite	1898	21,083,360
Hungary, coal	1898	1,239,498
,, lignite	1898	4,206,694
Belgium	1899	22,072,068
Borneo	1898	41,587
Bosnia	1898	271,184
Canada	1899	4,142,242
Cape Colony	1899	209,000
France	1899	32,933,788
Germany, coal	1899	101,621,866
,, lignite	1899	34,202,561
Greece	1898	17,310
Holland	1898	150,398
India	1899	4,937,000
Italy, lignite	1899	388,534
Japan	1897	6,000,000
Mexico	1898	126,251
Natal	1899	324,161
Peru	1898	10,000
Portugal, anthracite	1898	10,250
,, lignite	1898	12,291
Roumania, lignite	1898	67,000
Russia	1898	10,250,000
Servia	1896	11,726
South African Republic	1898	1,953,026
Spain	1899	2,742,389
Sweden	1899	239,344
United States	1899	226,553,564

A similar summary showing the production of pig iron is as follows:—

Country.	Year.	Production in Tons.
United Kingdom	1899	9,421,435
Austria	1898	957,836
Hungary	1898	469,404
Bosnia	1898	15,366
Belgium	1899	1,024,756
Canada	1899	94,077
France	1899	2,567,388
Germany and Luxemburg	1899	8,143,132
Italy	1898	12,387
Japan	1897	57,678
Russia	1898	2,193,750
Spain	1899	295,840
Sweden	1899	497,727
United States	1899	13,620,703

Iron Consumption.—According to the calculations of the Society of German ironmasters,* the production of pig iron per head of population in 1899 was as follows:—

	Lbs.
Germany	330
Great Britain	505
France	145
Austria-Hungary	67
Belgium	322
Sweden	244
Italy	1
Russia	46
United States	405

Imports and Exports.—Official statistics † show that the imports (in tons) of the leading European iron-producing countries in 1899 were:—

Country.	Iron Ore.	Pig Iron.	Iron and Steel.
Great Britain	7,055,178	248,706	396,324
Germany	4,165,372	677,134	160,643
Austria-Hungary	212,412	126,370	35,559
France	1,950,665	181,476	60,626
Belgium	2,620,750	432,920	76,986

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* *Verein Deutscher Eisen und Stahl Industrieller*, 1900, No. 18.

† *Ibid.*, 1900, No. 18, p. 88.

The exports during the year were as follows:—

Country.	Iron Ore.	Pig Iron.	Iron and Steel.
Great Britain	..	1,824,276	1,893,340
Germany	3,119,878	258,632	1,244,303
Austria-Hungary	326,834	27,737	80,239
France	291,346	535,463	124,390
Belgium	318,484	45,925	648,586

World's Production of Iron Ore.—In a course of lectures on metalliferous deposits, Bennett H. Brough * gave details of the principal iron ore deposits of the world. He showed that in 1854 the world's production of pig iron amounted to 6,000,000 tons.. Of that quantity the United Kingdom produced 50 per cent., France 12·5 per cent., the United States 12·5 per cent., and Germany 6·6 per cent. In 1898 the world's production had risen to 35,741,000 tons, of which the United States produced 32·7 per cent., the United Kingdom 24·1 per cent., Germany 20·6 per cent., and France 7·1 per cent. The relative position of the different countries from a mining point of view is better shown by the statistics of iron ore production. The world's production in 1898 was 73,670,000 tons, of which the United States produced 26·2 per cent., Germany 21·6 per cent., the United Kingdom 19·3 per cent., Spain 9·7 per cent., France 6·2 per cent., Russia 5·6 per cent., Austria-Hungary 4·5 per cent., and Sweden 3·1 per cent. The more important iron ore deposits now worked are at the mines of Lake Superior, Bilbao, Southern Spain, the Ural, Styria, Dannemora, Grängesberg, and Gellivare.

World's Production of Steel.—The following figures of the world's production of steel are given: †—

Country.	1898.	1899.
	Tons.	Tons.
Great Britain	4,565,300	4,855,325
United States	8,829,500	10,533,670
Germany	5,734,307	6,290,434
France	1,441,633	1,529,182
Belgium	653,130	729,920
Austria-Hungary	860,000	950,000
Russia	1,153,000	1,250,000
Sweden	265,121	257,000
Italy	60,000	80,000
Spain	90,000	120,000
Totals . .	23,651,991	26,595,531

In 1880 the total world's production was 4,192,008 tons. At the present time 70 per cent. of the pig iron made is converted into steel.

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* *Journal of the Society of Arts*, vol. xlviii. pp. 705–719.

† *Moniteur des Intérêts Matériels*, vol. l. p. 1327.

World's Production of Petroleum.—In a paper by Oebbeke,[*] the world's production of petroleum last year is stated to have been as follows:—

	Tons.
Russia	8,960,000
United States	8,745,000
Galicia	350,000
Sumatra	327,000
Roumania	300,000
Canada	110,000
Java	101,000
India	57,000
Japan	30,000
Germany	26,500
Peru	11,360
Italy	3,790

The consumption is estimated at:—

	Tons.
England	803,425
Germany	587,444
Japan	202,112
China	168,522
Brazil	77,824
Australia	77,575
France	48,583

World's Production of Nickel and Aluminium.—The world's production of nickel and aluminium has been as follows in the years mentioned:—

	Production.			
	1896.	1897.	1898.	1899.
	Metric Tons.	Metric Tons.	Metric Tons.	Metric Tons.
Nickel	4427	4758	6898	7350
Aluminium	1660	3394	4034	5748

The value of the nickel made in 1899 was about £920,000, and of the aluminium £630,000.†

The World's Miners.—The number of persons at the present time occupied in mining throughout the world is estimated † at 4,355,204. Great Britain heads the list with 875,603. Then follows Germany with 498,569, the United States with 444,578, India with 310,888, Ceylon with 310,210, France with 292,227, Belgium with 160,150, and Japan with 118,517. Before the war the Transvaal had 100,000 miners.‡

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[*] *Glückauf*, vol. xxxvi. pp. 636 639.

† *Stahl und Eisen*, vol. xx. pp. 1122–1123.

‡ *Der Gnom*, August 4, 1900.

A number of suggestions for improved coal-mining accident statistics are made by F. L. Hoffman.* Numerous tables are given to show the method preferred. The same subject is similarly treated by B. M'Laren; † and G. Farmer ‡ also contributes a paper on the question.

The World's Railways.—At the end of the year 1898 the total length of the world's railways was 752,472 kilometres § (1 kilometre = 0·63 mile). This total railway length only refers to the total length of the railways laid, and does not take into account the number of different lines of rails on the same track. Of the total length, 386,732 kilometres were in America and 269,743 in Europe. The area of the latter is, however, only about one-fourth of that of the former. Then follows Asia, which, despite its enormous area, has only the relatively small length of 55,605 kilometres, while Australia has the relatively much larger length of 23,334 kilometres. Africa had only 17,058 kilometres of railways. Details are given as to the length of lines in all the different countries. In Europe, Belgium has relatively the greatest length of line, having 20·6 kilometres of railway for each 100 square kilometres of area. The United Kingdom has 10·9 kilometres of line for the same area, Germany 9·2, Switzerland 8·9, the Netherlands 8·8, and France 7·9. The total length in the United Kingdom was 34,668 kilometres, in Austria-Hungary 35,113, in the British East Indies 35,384, in France 41,703, in Russia and Finland 42,535, and in Germany 49,560 kilometres. The United States had as much as 299,911 kilometres of railways. Since 1890 the progress in railway construction has been a fairly steady one, as the following table shows:—

End of the Year.	Total Length of all Railways.	Increase as Compared with the Preceding Year.	
	Kilometres.	Kilometres.	Per Cent.
1890	615,927	19,843	3·3
1891	635,891	19,964	3·2
1892	654,528	18,637	2·8
1893	671,893	17,365	2·6
1894	687,505	15,612	2·3
1895	700,631	13,126	1·9
1896	716,393	15,762	2·2
1897	733,789	17,396	2·5
1898	752,472	18,683	2·5

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* *Engineering and Mining Journal*, vol. lxix. pp. 650, 709.

† *Transactions of the Institution of Mining Engineers*, vol. xix. pp. 21–40.

‡ *Ibid.*, pp. 72–81.

§ *Archiv für Eisenbahnwesen; Stahl und Eisen*, vol. xx. pp. 904–907.

The average cost of the kilometre of line in Europe is placed at £14,502, while the total cost of all the lines of railway in the world is estimated at as much as £7,439,599,356. Detailed statements as to all the different countries are shown in tabular form.

The World's Iron Trade.—H. J. Skelton* discusses the competitive outlook in the world's iron and steel trades, particularly for the British iron trade, and gives the statistical position of the principal iron-producing countries of the world as follows:—

		1895. 1=1000 Tons.	1899. 1=1000 Tons.	Increase per Cent.
United Kingdom—				
Output of coal		189,661	220,085	16·6
Make of pig iron		7,703	9,305	20·7
Make of steel		3,289	4,855	47·6
Export of iron and steel		2,835	3,717	30·7
Consumption of iron ore		17,500	20,482	17·04
Value of iron and steel exports	£	19,680	28,093	42·2
Value of machinery exports	£	17,300	19,650	13·5
Ships launched		951	1,713	25·02
Germany—				
Output of bituminous coal		79,169	101,621	28·3
Make of pig iron		5,464	8,117	48·5
Make of steel		3,961	6,290	58·8
Exports of iron and steel		1,528	1,244	12·0
Output of iron ores		12,349	17,989	45·6
Value of iron and steel exports	£	...	18,174	...
Value of machinery exports	£	...	9,982	...
Tonnage of machinery exports		158	226	43·0
United States—				
Output of coal		172,500	230,800	33·4
Make of pig iron		9,446	13,621	44·7
Make of steel		6,115	10,150	65·9
Exports of iron and steel		...	779	...
Consumption of iron ores		17,253	22,000	27·5
Value of iron and steel exports Value of machinery exports	$	32,000	150,000	368·7
Belgium—				
Output of coal		20,457	21,918	71·4
Make of pig iron		829	1,036	24·9
Make of steel		454	730	60·7
Exports of iron and steel		489	610	24·7
Consumption of iron ores		2,282	2,903	27·2
Value of iron and steel exports	£			

The main points in which Great Britain is behind her principal competitors are:—Scientific organisation, economy of transport, use of machinery, and training of workmen, and these are discussed in some detail. The necessity for standard sections is strongly insisted upon.

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* Paper read before the British Iron Trade Association, through the *Iron and Coal Trades Review*, vol. lx. pp. 1125-1127.

Sir John J. Jenkins* discusses the questions of British traders and British railways with reference to the control and the cost of mineral transport.

J. Birkinbine† gives a table showing the world's production of iron ore, manganese ore, and pig iron, and offers some remarks on the distribution of the production in the various countries of the world, and on their capabilities in the present and future.

J. S. Jeans‡ discusses the iron situation from a British point of view, and especially refers to competition and the supply of ore.

G. H. Hull§ treats of industrial depression and the pig iron reserve.

H. J. Skelton‖ deals with the factors tending to develop the iron trade, particularly in the United States.

The World's Coal Supplies.—F. E. Saward¶ discusses the world's need of coal and the United States' supplies, especially in view of the increasing use and export of coal from America.

B. Taylor** also deals with the world's supply of coal, giving statistics of production and exports of Great Britain, America, and other countries.

Some notes on the competition of American coal in Europe are given,†† and statistics of the production and exports of the United States and Great Britain are appended.

The world's production of coal and the production of the leading countries is shown ‡‡ in a graphical form for the years 1883–1899.

Norton H. Humphrys§§ discusses how the increased price of coal has affected gasworks, and suggests means of covering the increase in expenditure without raising the price of gas.

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* Paper read before the British Iron Trade Association, through the *Iron and Coal Trades Review*, vol. lx. pp. 1123–1125.

† *Transactions of the American Institution of Mining Engineers*, Washington meeting, February 1900.

‡ *Engineering Magazine*, vol. xix. pp. 577–582.

§ *Ibid.*, pp. 641–654.

‖ *Ibid.*, vol. xx. pp. 9–16.

¶ *Ibid.*, pp. 1–8.

** *Cassier's Magazine*, vol. xviii. pp. 393–402.

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Printed by Ballantyne, Hanson & Co.
Edinburgh & London

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